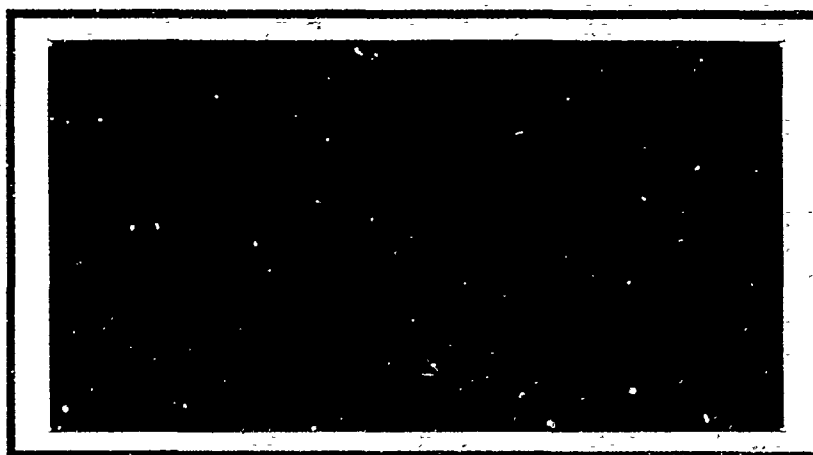


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APPLICATION OF INFLUENCE DIAGRAMS
IN
IDENTIFYING SOVIET SATELLITE MISSIONS

THESIS

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APPLICATION OF INFLUENCE DIAGRAMS
IN
IDENTIFYING SOVIET SATELLITE MISSIONS

THESIS

Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the
Requirements for the Degree of
Master of Science (Space Operations)

Cary C. Chun, M.S.

Captain, USAF

December, 1990

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Cary C. Chun

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Abstract


^{thesis}
 This ~~study~~ investigates the feasibility of applying influence diagrams to capture expert knowledge and incorporate decision theory to construct a Soviet satellite mission prediction model. Before a Soviet launch occurs, formulation of the model's prior probability distribution allows the input of expert knowledge and any available information. As the predictive variables of the model become known, the information is used to successively refine the estimate of the probable mission, thereby, reducing the uncertainty in the model. *Discretizing* is used to approximate continuous variables as discrete variables which successfully allows the combination of both variable types in a single influence diagram model. Results of testing and recommendations for continued research are presented.

Key words: Satellite identification, Space surveillance. (KQ) ←

APPLICATION OF INFLUENCE DIAGRAMS IN IDENTIFYING SOVIET SATELLITE MISSIONS

I. Introduction

1.1 Background

The United States must be able to quickly assess probable missions of foreign launches to react to any potential threat posed by such systems on U.S. national security. The Foreign Technology Division (FTD) at Wright-Patterson AFB, OH is an Air Force organization tasked with assessing foreign technological capabilities. An area of particular interest is Soviet satellite systems. FTD has suggested that thesis research be accomplished in the development of a model which can serve as a predictive tool in determining possible Soviet satellite missions.

The Space Surveillance Center (SSC), located at the Cheyenne Mountain Complex in Colorado Springs, Colorado, is the Air Force organization primarily tasked with Soviet satellite identification. To operationally fulfill this mission, the SSC accomplishes the following:

Detects, tracks, identifies, and maintains surveillance on all man-made objects in earth orbit through tasking requirements levied on sensors; maintains an accurate current catalog of all space objects; and provides orbital data on space objects to military, civilian, and scientific agencies.
(28:1.11)

Previous approaches to mission identification included expert systems and statistical analyses techniques. These models are discussed in the literature review.

The models developed from this research used various techniques to predict possible satellite missions. The end result produced by each model was the identification of the most likely satellite mission. This thesis applied a different methodology and quantified the prediction by determining the specific probabilities associated with each possible mission area. The model evaluated information that was available before a particular launch occurred and formulated the possible prior probabilities associated with that specific launch. For example, prior information might include the knowledge that a Soviet communication satellite has exceed its lifetime and must be replaced or that the Soviets need to monitor the sudden occurrence of a localized crisis in a geographic location where they currently have no satellite coverage. Historical data was then be used to define the relationships that existed between the data variables. Once these relationships were defined, the necessary information was extracted to predict the possible missions associated with a launch. Quantification and augmentation of this information increased the predictive power of the model.

Influence diagramming is a method which allows the simple construction of a model to illustrate the interrelationships which exist among variables by capturing an expert's knowledge and translating that knowledge into the model. A computer is then able to mathematically manipulate the data to extract the needed information in a format suitable to a decision maker.

1.2 Objective

The objective of this research is to investigate the feasibility of applying influence diagrams to capture expert knowledge and incorporate decision theory to construct a Soviet satellite mission prediction model. This investigation specifically determines the feasibility of using revealed information to successively refine the estimate of the probable mission.

II. Literature Review

2.1 Introduction

The purpose of this literature review is to evaluate the tool, *influence diagrams*, to be used in the development of the predictive model and also evaluate the previous research accomplished in the area of satellite mission prediction.

2.2 Influence Diagramming

2.2.1 Overview. An influence diagram is a graphical network representation for modeling uncertain variables and decisions and explicitly revealing probabilistic dependence and the flow of information (24:871). The influence diagram provides a new language for communication between the decision maker and the decision analyst and allows the creation of models that are easy to understand and mathematically concise for computer manipulation. This concept has developed into a modeling language which improves upon the use of decision trees. Influence diagrams also provide a means of representing the important variables in the model and their interrelationships in a graph-theoretic manner. "Influence diagrams are hierarchial, containing a top level graph with data as the second level" (27:2). At the graph level, variables in the model are represented as nodes and the influences among those variables are represented by directed arcs. At the second level, the data is represented in a form which expresses the mathematical relationships existing among the variables. After modeling the problem as an influence diagram, probabilistic relationships can be manipulated at the graph level of the diagram (23:402). Using the computer to manipulate the data allows for assessment of the model in a form understandable to the decision maker.

2.2.2 Purpose. Since its inception in 1976, influence diagrams have proven to be a very resourceful tool in the representation of probabilistic and decision anal-

ysis models (24:871). Howard and Matheson described the concept as a new type of modeling description that is very easily comprehended even by an individual with a limited technical background. Influence diagramming is also formally structured mathematically for computer interpretation. Thus, influence diagramming "...forms a bridge between qualitative description and quantitative specification (7:721)." Howard and Matheson specified that the purpose of influence diagramming is to provide a technique which allows the decision maker to probabilistically model a decision and gather the necessary data, and then allow an automated system to complete the mathematical analysis. The authors demonstrated the procedures of model formulation and then presented the process of converting the influence diagram to a decision tree network. The decision tree network represents the problem in a form conducive for computer manipulation (7:740-762).

In contrast to Howard and Matheson's contention that influence diagrams bridge the gap between humans and a computer system, Owen asserts that influence diagrams serve as a communication tool between a decision analyst and the decision maker. He describes this process as participative modeling versus interactive modeling (22:765). In the procedure of participative modeling, the influence diagram is constructed jointly with the decision analyst by first defining the value associated with the outcomes of the decision and then working backwards to identify the preceding variables which have influence on the outcomes (22:767). Additionally, in his research, Owen discovered that when a decision maker identified an influence among variables in a problem, the influence represented a probabilistic dependence. "Furthermore, influences that were identified as 'strong' represented, roughly speaking, more probabilistic dependence than influences that were identified as 'weak'" (22:767). This method of communication provided a means by which a decision maker untrained in the art of modeling could express his/her perception of the decision model to an analyst who could then interpret and measure the decision maker's intended relationship between the variables. However, Owen identified a deficiency

in this problem representation method concerning the quantification of the existing influence because there is no "...mathematical expression corresponding to the intuitive notion of the strength of an influence, and in some instances the relative strengths of two influences may be ambiguous (22:768)." In this instance, some formal method of quantifying the relationship must be applied to effectively measure and accurately represent the influences.

2.2.3 Development and Formalization. The first attempts to formalize the concept of influence diagrams were accomplished by Howard and Matheson in 1981 as founders and directors of the Strategic Decisions Group. The Strategic Decision Group is a company which "...specializes in helping capital-intensive, risk-intensive, and research intensive companies analyze their most critical decisions, develop strategies, and create business opportunities" (7:i). Both authors have extensive experience in the discipline of decision analysis. In their publication, they defined the basic components and the variable relationships represented by the influence diagram (7:735-737). *Chance nodes* are represented by circles and *decision nodes* are represented by boxes/squares. The uncertainty in the model is represented by chance nodes which are essentially random variables having an associated probability distribution. Decision nodes represent the various decisions that are to be made in the model. Howard and Matheson define two arrows/arcs which indicate the two types of influence which can exist between two nodes. *Informational influences* are represented by arrows into a decision node and graphically show which variables will provide known information at the time when the decision is made (7:735). *Conditioning influences* are graphically represented by arrows into chance nodes and "...show the variables on which the probability assignment to the chance node variable will be conditioned" (7:735). Howard and Matheson also define the basic rules for graphically manipulating the diagram to form a representation that is suitable for assessment purposes and, at the same time, preserves the inherent mathematical value of the model (7:732). This is an important advantage in modeling the problem

since it allows the decision maker to manipulate the graph and isolate the variables and influences of interest to assess the model. Reversing the direction of the arcs between two chance nodes in the diagram is accomplished by the application of *Bayes' theorem*.

Building upon the work of Howard and Matheson, Shachter developed formal definitions of the graphical manipulations. He formed theorems for each process and provided mathematical proofs supporting each one (24:876-879). These theorems include the removal of chance nodes, removal of decision nodes, and the reversing of the arc directions. Based upon these rules, Shachter developed algorithms for solving influence diagrams. These algorithms provide a foundation for computer manipulation of influence diagrams. Shachter also introduces a third node. He graphically represents the *value node* as a rounded rectangle; however, today's most common representation is a diamond. The value node represents the decision maker's utility associated with a specific decision and the arcs into value nodes represent the attributes of the utility function (24:873).

Up to this point in time, influence diagrams had been used primarily as a communication tool for structuring models and representing dependencies among variables and information flow. In another publication, Shachter provides a methodology for applying influence diagrams to probabilistic inference models. A probabilistic model represents a problem in which an inference must be made based upon the available probability distributions and known observations of the critical variables represented in the graph (23:406). An influence diagram is termed probabilistic if all the variables in the model represent constants or uncertain quantities (26:590). Additionally, each node, at the secondary data level of the diagram contains the variable's associated data represented as a set of outcomes with a conditional probability distribution corresponding to those outcomes (26:590). Shachter introduces a fourth node called a *deterministic node* which is graphically represented as a double circle. The deterministic node represents a variable whose value is certain given the

value of the preceding conditional variables (26:509). Shachter formalizes the procedures for manipulating the influence diagram of inference models and provides the proofs and associated algorithm for solving such models (26:594-597). Furthermore, an algorithm is presented which determines the minimum information requirements of the nodes for solving probabilistic inference model (26:599).

In the first article above by Shachter, he proposes that further research be accomplished to improve his algorithm by developing a procedure which optimizes the sequence in which node reductions are accomplished (24:882). Rege and Agogino introduced the *greedy algorithm* in their use of influence diagrams for developing expert systems. The authors argued that Shachter's goal-directed algorithm did not include any complexity analysis (23:406). One purpose of their research was to develop an efficient algorithm which could be applied to large complex problems. They developed an algorithm capable of solving inference problems by applying a search heuristic that keeps the required number of mathematical operations to a minimum. The "...greedy algorithm performs operations in the order of estimated least cost" (23:406). The authors showed that this algorithm does not guarantee that the operations will be performed in an optimal sequence; however, it does minimize the number of required arc reversals for removing a node (23:406).

Until now, the application of influence diagrams in representing the modeled variables has been limited to discrete probability distributions. In the latest development in the area of influence diagramming, Shachter and Kenley present a *linear-quadratic-Gaussian model* for applying influence diagramming theory for representing continuous variables (25:527). An influence diagram becomes a *Gaussian* probabilistic influence diagram if "...the joint probability distribution for the variables in the model is multivariate normal" (25:528). In other words, the conditional probability distribution of all the variables being analyzed is represented by a normal standard distribution with a mean and conditional variance and the associated influence is represented by a linear coefficient (25:529).

2.2.4 *Apphcation.* This research applied influence diagrams to construct a prediction model. Two models which previously applied this concept are now presented. Narchal, Kittappa, and Bhattacharya incorporated influence diagrams in their application of a long-range planning system called *Business Environment Scanning System for Corporate Planning* (20:96). Since the success of a business organization is heavily dependent upon the nature of the environment it encounters, it is essential that the organization thoroughly understand the environment in which it currently operates and be able to predict the condition of that environment in the future. Based upon such an assessment, the organization can adapt and determine the strategic movement to undertake which will ensure corporate success. This is the reason why "...most practitioners in corporate planning have been devoting attention to Business Environmental Scanning as an important aspect of corporate planning (20:96)." Therefore, the authors stress the need to be constantly aware of those environmental descriptors which reveal the developments, trends, and events in the environment and allow the Business Environmental Scanning System to generate signals which indicate possible threats or opportunities existing in an environmental area (20:98). These environmental descriptors are linked to the long-range planning system through environmental indicators and influence diagrams. For example, the article illustrates how factors such as demand, supply, and manufacturing costs influence the price of raw materials (20:100).

Once the Environmental Descriptor in different Environmental Areas is continuously monitored and the Influence Diagram for different Environmental Indicators are ready, the system serves as an Early Warning System for the Corporate Planning group to plan the right strategies and quantum of strategic thrust it has to give in the different areas of the company. (20:99)

The authors point out a limitation to their system by indicating that the relationships of the variables in the model are heavily dependent upon the accurate representation

of an expert's opinion. "The reliability of the system, therefore, depends on the efficacy and the depth of the Influence Diagram" (20:104). In another application of influence diagrams for predicting future conditions, Britto and Oliver applied the technique in their analysis of forecasting donors, gifts, and cumulative private donations to an educational fund in the College of Engineering at the University of California, Berkeley (4:39). The authors constructed an influence diagram to analyze the relationship among potential donors, non-donors, new donors, and the cumulative number of donors. The model showed that "... the number of non-donors is influenced by the total donor potential N and the cumulative donors" (4:42).

In an application that supports Owen's contention that influence diagramming is a modeling language used to communicate between individuals, Howard introduces the concept of Knowledge Maps. Each individual possesses a vast amount of knowledge in many different areas. The challenge which faces individuals is to assemble that knowledge into a recognizable form which is suitable for assessment purposes.

The knowledge we have about any uncertain event is composed of many fragmented pieces of information that are relevant to the event in question. The fragments of information may exist in one person or among several people. We face the problem of how to gather and coordinate these fragments to form a coherent probability assignment. (8:903)

Influence diagrams provide a means for constructing knowledge maps that will help an individual effectively compile information from a diverse group of information sources. An influence diagram composed of chance nodes and arcs is called a relevance diagram (8:904).

A knowledge map is a relevance diagram constructed to capture the knowledge of an individual, its author. The author may be able to consult with a group of experts who can assess probability assignments that he will accept as his own in the knowledge map. (8:905)

Through a number of illustrative examples, Howard demonstrates the process of constructing knowledge maps with influence diagrams. By identifying various pieces of information related to the problem, an individual can then attempt to organize these variables by defining the relationships among each of them. This process allows the construction of an influence diagram which assists the individual in organizing the fragmented information into a useful form.

Directly related to the area of knowledge mapping, Rege and Agogino, mentioned earlier for the "greedy" algorithm, applied influence diagrams as a means to capture the type of knowledge required in the formulation of expert systems. "The representation and management of uncertainty is a critical issue in the development of expert systems (23:402)." The authors demonstrated how influence diagrams can accomplish this task by formulating the process of capturing the knowledge of an expert and representing it in the influence diagram framework. The process was then illustrated in the modeling of an expert system for purchasing a used car (23:409).

2.3 Satellite Mission Prediction

Past research has been accomplished in the area of satellite mission identification. Currently, the SSC uses a software program, **AUTOLAUNCH**, developed by Teledyne Brown, to assist in mission identification. AUTOLAUNCH requires the input of launch information to select a specific *launch folder* which identifies possible missions based upon historic launch parameters. A decision rule based expert system was developed which models the mission identification procedures used by the SSC (19). Another model applied statistical analysis techniques for identifying satellite missions (19). The specific techniques used were multiple discriminate, factor, and cluster analysis.

2.4 Summary

This literature review on influence diagrams discussed the dual purpose of this technique, the evolution of its development and formalization, and the various applications of this concept. Influence diagrams provide a means for representing a model in an easy-to-understand graphic network which is also formally expressed for computer manipulation. They also serve as a modeling language which allows communication between the decision maker and decision analyst for jointly modeling the problem. Since its introduction, influence diagrams have evolved from a communication tool to a formalized analytical tool for evaluating probabilistic inference and decision analysis models. The technique of influence diagramming is now formalized by mathematical theorems, corollaries, and propositions, and includes a number of algorithms which allow automated systems to solve the mathematical manipulations. The application of influence diagrams extends beyond the scientific community and its use can be seen in today's business sector. Finally, previous approaches to the mission identification problem included expert systems and statistical analyses.

III. Methodology

3.1 Introduction

This chapter will describe the methodology that was applied towards the research objective. The research centers on the application of influence diagramming and solving such diagrams to extract information specifically formatted for the decision maker. The literature review in the previous chapter cites a number of references which can provide a more detailed and advanced explanation of these concepts than are presented in this research. The paragraphs that follow will address the methodology applied towards the resolution of the research objective. The methodology applied provides the reader with an initial understanding of influence diagramming formulation and resolution and also provides an overview of the Soviet space program.

3.2 Data Availability

It was necessary to obtain historical data on Soviet launches and satellite orbits in order to define the probabilistic relationships that exist among the variables in the model and examine how they each contribute towards predicting Soviet satellite missions. Several organizations were contacted to obtain this historical data.

3.3 Soviet Satellite Missions

The Soviet satellite missions had to be identified in order to construct the model for the influence diagram. Specific data required included mission descriptions, launch information, orbital parameters, and operational constellations. This information was needed to distinguish amongst the diverse number of Soviet satellite missions. The mission data was also required to help define decision thresholds in the probability calculations. *The Soviet Year in Space*, produced by Teledyne Brown,

contained the required information at the unclassified level. Additionally, personal interviews were conducted with experts in the field of Soviet satellite identification.

3.4 *Influence Diagram Model*

An overview of basic elements and operations of influence diagrams is presented followed by the construction of the model. Based upon the historical data and expert knowledge, the relationships that exist among each of the predictive variables were defined and represented graphically in an influence diagram. Upon examination of the predictive variables, it was obvious that some were *discrete* while others were *continuous*. The literature review revealed that influence diagrams are capable of manipulating models with discrete variables and that recent developments allow representation of continuous variables that are *Gaussian* in nature. However, to date, no algorithms exist that are able to manipulate both type of variables in a single model. Additionally, the influence diagramming software programs available for this research were designed for discrete variable application only. Therefore, it was necessary to apply a method called *discretizing* to convert the continuous variables to approximately discrete variables. In formulating *prior* probabilities for the model, heavy reliance is placed on expert opinion, historical trends, world situation, current Soviet requirements, and intelligence information. The influence diagramming software programs used include the *AFIT Influence Diagram System (AFids)* (3), developed by Captain Christopher T. Baron and *Influence Diagram Processor (InDia)*, developed by Decision Focus Incorporated. These software programs are capable of graphically representing the model and manipulating the data to obtain the desired probabilistic relationships. Finally, the model was validated and an analysis of the results was presented.

3.5 Summary

This thesis research demonstrated the ability of an influence diagram to capture the expert knowledge in the area of Soviet space systems and use the information to construct a mission prediction model.

IV. *Satellite Data and Mission Descriptions*

4.1 *Introduction*

This chapter will first discuss the availability of historical data on the Soviet Space program and the classification issues involved. Secondly, the chapter will provide descriptions of the various Soviet satellite systems and their associated launch and orbital parameters.

4.2 *Historical Data*

To identify data availability, contact was made with several organizations. The Space Surveillance Center maintains a database which contains the orbital parameters of past and present Soviet satellites. The data is represented in a *two-line orbital element set* which contains a number of parameters which characterize the orbit of an observed satellite. However, the element set does not identify an associated mission. If certain missions are provided with the element sets, the data may become sensitive to U.S. National Security and would therefore be classified SECRET ("Information such that unauthorized disclosure could reasonably be expected to cause Serious Damage to National Security (28:1.2).") or TOP SECRET ("Information such that unauthorized disclosure could reasonably be expected to cause Exceptionally Grave Damage to National Security (28:1.2)."). The Foreign Technology Division has access to this information. However, to avoid the administrative problems associated with using classified information, the predictive model was produced with data published in *The Soviet Year in Space*, by Nicholas L. Johnson, the Advisory Scientist for Teledyne Brown Engineering. This unclassified document contains launch data and orbital parameters of Soviet satellite systems as well as additional information which was used to formulate prior probabilities. This data represents the initial operational orbits of the associated launches. Five volumes (1985-1989) of this annually published document were obtained to extract the historical data for calculating the

probabilistic relationships among the variables of the model. The two line element sets from the SSC, that were mentioned above, were needed to supplement the data provided by the *Soviet Year in Space*. Specifically, the parameter *argument of perigee* was required to distinguish two Soviet missions. The data from 1990 launches was excluded in the development of the influence diagram model. Splitting the data at this point provided a subset for testing and validating the model. This test data is listed in Appendix C.

4.3 *Soviet Satellite Missions*

This section will provide a brief mission description of the various operational Soviet satellite systems. Additionally, possible launch sites, boosters, and orbital parameters for each mission will be presented. The information presented in this chapter, unless otherwise cited, was obtained from *The Soviet Year in Space 1989* (11). The reader is advised to refer to this document for more detailed mission and system descriptions.

It is estimated that about 80 percent of all Soviet space launches are related in some way to programs for national security: space-based reconnaissance, communications, navigation and missile early-warning satellites. About 10 percent are related to the support and operation of the space station. The remaining launches are devoted to automated scientific satellites, civil-communications satellites and navigation satellites.
(2:34)

Due to the Soviet's heavy reliance on space platforms to support its national security efforts, it is necessary to distinguish between the military and non-military related missions. It is important to understand the entire spectrum of the Soviet space program and how these assets support the Soviet military forces. Therefore, this section will also identify those missions that are military in nature.

4.3.1 Photographic Reconnaissance Satellites The greatest proportion of Soviet launches are from their photographic reconnaissance program, which accounted for 42% of the launches in 1989, slightly higher than that for the decade. The specific missions of these satellite systems cover a broad spectrum which includes strategic and tactical missions, and the monitoring of Earth resources. The Soviet mainly use these systems to continually monitor U.S. and NATO strategic forces. Tactical photography is utilized for monitoring specific regional areas of conflict throughout the world. Soviet tactical reconnaissance satellites have been utilized in Afghanistan, the Middle East, Africa, and Central America. Earth Resource satellites monitor the world-wide status of mineral and agricultural deposits. These multi-spectral Earth Resource imaging systems may also be used for military application and do occupy the same orbit as the military photographic systems. Therefore, for the context of this research, these systems will be classified as military systems. The Soviet photographic satellites consists of three generations which vary in technical capability as well as lifetime.

4.3.1.1 Third Generation. First and second generation photo reconnaissance satellite systems are no longer utilized in the Soviet reconnaissance program. All the Earth Resource satellite systems are third generation. Since the 1980's, all of these systems have been launched into high inclinations of 82-83 degrees from Plesetsk with an average lifetime of 19 days. The majority of the third generation systems are assigned military area and spot surveillance missions with average lifetimes of 12-16 days. The main disadvantage of these third generation satellites is the requirement to deorbit the entire spacecraft in order to process the film.

4.3.1.2 Fourth Generation. To overcome the deficiency of third generation satellites, the Soviets developed the fourth generation systems which allow for the ejection and deorbit of film capsules versus deorbiting the entire spacecraft. In addition, an improved average lifetime of 44-49 days was achieved.

4.3.1.3 *Fifth Generation.* In late 1982, the Soviets introduced their latest generation of photographic reconnaissance satellites with an improved average lifetime of 183 days. Mr. Johnson cites from the Director of U.S. Naval Intelligence, Rear Admiral Thomas A. Brooks, that the long lifetimes of these systems suggest that the data might be transmitted in real-time versus by the traditional physical means (11:37).

4.3.2 *Photographic Reconnaissance Orbits.* The Soviets utilize a number of highly inclined orbits, launched from Plesetsk and Tyuratam with varying eccentricities and altitudes. Table 1 lists, by generation, the various orbits used for photographic reconnaissance as of 1989. During that year, a change in orbits used by third generation photo reconnaissance satellites was witnessed. The Soviets abandoned the 70.4 and the 72.9 degree inclined orbits from Tyuratam and Plesetsk, respectively, and moved these missions to an orbit with an inclination of 62.8 degrees. Additionally, a fourth generation orbit of 70 degrees was chosen over the previous 64.9 degree orbit.

Table 1. Photographic Reconnaissance Orbits

INCLINATION (Launch Site)	ALTITUDE/ECCENTRICITY		
	LOW/CIRCULAR	LOW/ECCENTRIC	HIGH/CIRCULAR
50.6° (TT)		4th Generation	
62.8° (PL)	3rd Generation	3rd Generation 4th Generation	3rd Generation
64.8° (TT)	4th Generation 5th Generation	4th Generation	
67.1° (PL)		4th Generation	
70.0° (TT)	3rd Generation	3rd Generation 4th Generation	3rd Generation
82-83° (PL)	3rd Generation	3rd Generation	3rd Generation

Table 2. Photographic Satellite Launch Sites and Boosters

PROGRAM	LAUNCH SITE(S)	BOOSTER
3rd Generation	PL, TT	SL-4
4th Generation	PL, TT	SL-4
5th Generation	TT	SL-4

4.3.3 Communication Satellites. Due to the significantly large geographical expanse of the Soviet Union, which spans half the globe, communication throughout the country is major task. Nearly one-half of all operational Soviet satellites are devoted to communication missions. The Soviets satellite communication consists of three systems varying in altitude.

4.3.3.1 Low Altitude. The low altitude communication satellites consists of three separate constellations which comprise the Soviet's command, control, and communication network. D. Ball concludes, as described by Mr. Johnson, that the low altitude communication systems appear to provide delayed or near-realtime global communication relays from military and intelligence users to U.S.S.R. authorities (11:38). They employ a "store and dump technique" whereby the communications data is transmitted to the satellite which stores the data until it can be downlinked to a receiving ground station. The lowest of the three constellations consists of three planes that are spaced 120 degrees apart with each containing one satellite. They are launched from Plesetsk on SL-8 boosters into inclinations of 74 degrees, with a period of 101 minutes, a mean altitude of 800 km, and an average lifetime of 12-13 months. The remaining two low altitude constellations are multiple payload communication satellites. From a single launch, six or eight payloads are placed into orbit. The constellation utilizing the eight payload deployment consists of 24 satellites in a single plane with an inclination of 74 degrees, period of 115 minutes, a mean altitude of 1450 km, and an average lifetime of 16-18 months. This

constellation can provide approximately 17 hours of uninterrupted communications each day. Also, due to the number of satellites in the constellation, the loss of one or two satellites would have minimal effect on the operations of the system. The constellation which utilizes the six payload deployment is launched from Plesetsk on a SL-14 booster and is placed in a higher inclined orbit of 82.6 degrees with a period of 114 minutes, mean altitude of 1400 km.

4.3.3.2 Molniya. A *Molniya* orbit is one characterized by a high eccentricity (low perigee and very high apogee). This characteristic allows the communication satellite to remain over a particular geographical area for an extended period of time without having to be at a geosynchronous orbit. Additionally, it allows for area coverage at the northern latitudes. These communication satellites spend approximately eight hours a day at high altitudes over the northern hemisphere of the Soviet Union providing telephone and television services to the Soviet Union and Eastern Europe. The Molniya-1 constellation consists of 8 planes which are spaced 45 degrees apart with a single satellite per plane inclined at 62.8 degrees with a period of 718 minutes, a perigee of 400 km, and an apogee of 40,000 km. They are launched on SL-6 boosters from Tyuratam and Plesetsk. The Molniya-3 communication satellite system consists of two constellation of four planes spaced 90 degrees apart with one satellite per plane. The altitudes, inclination, and period are identical to those of the Molniya-1 satellite, however, Molniya-3 satellites have only been launched from Plesetsk on SL-6 boosters. The principle differences between the Molniya-1 and Molniya-3 satellites is that the former operates at higher communication frequencies and has a physically different solar array.

4.3.3.3 Geosynchronous. The Soviets were late in developing a geosynchronous communication system because of their investment in the Molniya program and because the geostationary orbit required a larger cost for boosting the payload to the high altitude. Additionally, the orbit can not service the higher northern

latitudes of the Soviet Union. As of 1989, geostationary communication satellites occupy 19 positions along the equator. These geostationary systems are launched from Tyuratam on SL-12 boosters to an inclination between zero and two degrees with a period of 1436 minutes and a mean altitude of approximately 35,785 km. The geosynchronous communication satellites are divided into four programs: Raduga, Ekran, Gorizont, and Kosmos.

- *Raduga*. The Raduga satellites occupy equatorial positions of 35, 45, 49, 70, 85, 128, 190, 335 degrees east. The Raduga satellite has not been publicly displayed, nor has its illustrations been released.

This Soviet reluctance has been interpreted in the West as evidence that Raduga satellites primarily serve military and government functions. Further supporting this theory are Soviet plans filed in the late 1970s to establish what the Russians call a Gals system of transponders for military/governmental communications at Raduga locations. Today every Raduga satellite is located at a registered Gals position. (11:43)

- *Ekran*. Three Ekran satellites occupy the same equatorial position of 99 degrees east and serve as a television and radio relay platform and also provides weather and oceanographic data to Soviet ships through the Arctic Television Information System.
- *Gorizont*. The Gorizont geosynchronous satellites are general purpose communication satellites which are very similar to the Molniya-3 satellites. Gorizont satellites support the following: U.S.- U.S.S.R. hotline, the INMARSAT maritime communication network, the international Intersputnik telecommunications system, the Soviet national Moskva television system, and the new Moskva-Globalnaya system. In addition to these missions, transponders are available for commercial use. These Gorizont satellites occupy equatorial positions of 40, 53, 80, 90, 96.5, 103, 140, 190, 346, and 349 degrees east.

- *Kosmos*. The fourth generation of geosynchronous communication satellites are listed under the Kosmos name and have been involved in missions associated with data relay for the Soviet *Satellite Data Relay Network* similar to that of the U.S. *Tracking and Data Relay Satellite System (TDRSS)*. These Kosmos satellites occupy geostationary positions of 80, 95, 335, and 346 degrees east.

Table 3. Communication Satellite Orbits

PROGRAM	APOGEE (km)	PERIGEE (km)	INCL (deg)	PERIOD (min)	CONSTELLATION
Low Alt-1	810	790	74	101	3 planes spaced 120° 1 satellite per plane
Low Alt-2	1,550	1,350	74	115	24 satellites in 1 plane
Low Alt-3	1,415	1,385	83	114	2 planes spaced 90° 6 satellites per plane
Molniya 1	40,000	400	63	718	8 planes spaced 45° 1 satellite per plane
Molniya 3	40,000	400	63	718	4 planes spaced 90° 1 satellite per plane
	40,000	400	63	718	4 planes spaced 90° 1 satellite per plane
Geo-synchronous	35,785	35,785	0-2	1436	19 locations above the equator

4.3.4 *Navigation Satellites*. Of all space systems the Soviet Union currently operates, none is more duplicative of a U.S. system than their navigation systems. The Soviet low altitude navigation system is very similar to the American Transit system and the Soviet *Global Navigation Satellite System (GLONASS)* is very similar to the U.S. *NAVSTAR Global Positioning System (GPS)*.

Table 4. Communication Satellite Launch Sites and Boosters

PROGRAM	LAUNCH SITE(S)	BOOSTER
Low Alt-1	PL	SL-8
Low Alt-2	PL	SL-14
Low Alt-3	PL	SL-8
Molniya-1	PL, TT	SL-6
Molniya-3	PL	SL-6
Geosynchronous	TT	SL-12

4.3.4.1 Low Altitude Navigation. The Soviet low altitude navigation system consists of two constellations which operationally complement each other. The military constellation has six orbital planes which are spaced 30 degrees with a single satellite in each plane and the civilian constellation only consists of four planes spaced 45 degrees apart, also with a single satellite in each plane launched from Plesetsk on a SL-8 booster. Both constellations possess orbits with an inclination of 83 degrees, period of 105 minutes, perigee of 965 km, and apogee of 1020 km. Both systems are used primarily by the Soviet navy and maritime ships for geographical coordinates. In addition, the civilian satellites possess transponders for use by the international search and rescue system (U.S.S.R. - COPAS and U.S. - SRSAT). Since both low altitude constellations are in the same orbit, separated only by right ascension degrees, it would be possible to design ground equipment compatible to the transmission formats and frequencies of both constellations, significantly increasing ground coverage. Therefore, both systems will be categorized as having military missions.

4.3.4.2 Global Navigation Satellite System. An unprecedented step towards a joint operational space system was taken by the agreement to merge U.S. and Soviet navigation system. This was reported by *Izvestiya* and described by Mr.

Johnson as follows:

The similarity of GLONASS and the American GPS permits the construction of receivers which can access either system. This concept of a unified space-based navigation system was taken a step forward in 1989 when the United States and the Soviet Union agreed to coordinate the GPS and GLONASS operations for the international community. (11:52)

GLONASS satellites are launched as multiple payloads (three per launch) on SL-12 boosters from Tyuratam. However, in 1985, there were three launches with unknown boosters. The GLONASS constellation contains three planes spaced 120 degrees apart with three or more satellites in each plane in inclined orbits of 65 degrees with periods of 676 minutes and a mean altitudes of 19100 km.

Table 5. Navigation Satellite Orbits

PROGRAM	APOGEE (km)	PERIGEE (km)	INCL (deg)	PERIOD (min)	CONSTELLATION
Low Alt-1	1,020	965	83	105	6 planes spaced 30° 1 satellite per plane
Low Alt-2	1,020	965	83	105	4 planes spaced 45° 1 satellite per plane
GLONASS	19,200	19,000	65	676	3 planes spaced 120° 3 or more satellites per plane

Table 6. Navigation Satellite Launch Sites and Boosters

PROGRAM	LAUNCH SITE	BOOSTER
Low Alt-1	PL	SL-8
Low Alt-2	PL	SL-8
GLONASS	TT	SL-12

4.3.5 *Geodetic Satellites.* Geodetic satellites are very similar to the navigation satellites and are used primarily to map the Earth's shape and measure its gravitational field. However, in addition to the scientific uses such as earthquake prediction, the data collected is used in calculating targeting parameters for long range tactical and strategic weapons. Therefore, their missions will be classified as military. The low altitude geodetic satellites are launched from Plesetsk on SL-14 boosters into inclinations of 73.6 or 82.6 degrees with a period of 116 minutes and a mean altitude of 1500 km. Two higher latitude geodetic satellites were launched with GLONASS navigation satellites and are in identical orbits.

Table 7. Geodetic Satellite Orbits

PROGRAM	APOGEE (km)	PERIGEE (km)	INCL (deg)	PERIOD (min)
Low Alt-1	1,503	1,498	82.6	116
Low Alt-2	1,526	1,480	73.6	116
High Alt	19,200	19,000	65.0	676

Table 8. Geodetic Satellite Launch Sites and Boosters

PROGRAM	LAUNCH SITE	BOOSTER
Low Alt-1	PL	SL-14
Low Alt-2	PL	SL-14
High Alt	TT	SL-12

4.3.6 *Meteorology Satellites.* The Soviet meteorological satellites are able to provide more than cloud coverage photography. This was revealed from a direct quote Mr. Johnson obtained from a Soviet national paper, *U.S.S.R., Second United Nations Conference on the Exploration and Peaceful Uses of Outer Space* which reads as follows:

- (a) twice a day information on distribution of cloudiness and ice and snow cover over the Earth as TV-images in visible and IR-bands;
- (b) twice a day global data on temperature fields and cloudtop heights, as well as on water surface temperatures;
- (c) twice a day global information on the radiation situation in near space;
- (d) two or three times a day TV-images of cloud, ice and snow covers in areas of 6-7 million km² each, being received in any region of the Earth at self-contained receiving points. (11:55)

Soviet meteorology satellite system consists of two constellations, each with a single satellite per plane spaced 60 degrees apart. The Meteor 2 and 3 satellites differ in mean altitude at 950 and 1240 km, and in period at 104 and 110 minutes, respectively, but share the same inclination of 83 degrees. Both systems are launched from Plesetsk on SL-14 boosters.

Table 9. Meteorological Satellite Orbits

PROGRAM	APOGEE (km)	PERIGEE (km)	INCL (deg)	PERIOD (min)	CONSTELLATION
Meteor 2	960	940	83	104	3 planes spaced 60° 1 satellite per plane
Meteor 3	1,250	1,230	83	110	3 planes spaced 60° 1 satellite per plane

Table 10. Meteorological Satellite Launch Sites and Boosters

PROGRAM	LAUNCH SITE	BOOSTER
Meteor 2	PL	SL-14
Meteor 3	PL	SL-14

4.3.7 Remote Sensing Satellites. The technology of remote sensing allows a country to monitor its own natural resources, as well as those of other countries.

The evaluation of earth resources is an important part of the Soviet space program because of its dollar savings. For the mission description, Mr. Johnson quotes I. Yegorova and Yu. Zaytsev in *Politcheskoye Samoobrazovaniye*, which reads as follows:

Remote sensing saves the Soviet economy an estimated 500-600 million rubles a year by assisting "agriculture and forestry, geology and mineral surveys, hydrology and water resource management, oceanography and evaluation of marine resources, geography and control of the environment." (11:59)

The Soviet's remote sensing program can be divided into the following classes: *Resurs-F*, *Resurs-0*, *Okean-0*, *Almaz*, and *Prognoz*.

4.3.7.1 *Resurs-F*. *Resurs-F* remote sensing satellites were mentioned earlier in the photographic reconnaissance section. These satellites are third generation photo reconnaissance satellite used to monitor earth resources. However, their high resolution allows for the capture of military data and are therefore included in that section.

4.3.7.2 *Resurs-0*. The *Resurs-0* satellites are very similar to the U.S. *Landsat* satellites and utilize multi-spectral sensors in an inclined orbit of 98 degrees with a period of 98 minutes, and a mean altitude of 640 km. From this orbit, *Resurs-0* satellites are able to monitor land masses and oceans world-wide. The *Resurs-0* satellites are launched from Tyuratam on a SL-3 booster.

4.3.7.3 *Okean-0*. The *Okean-0* is an oceanographic satellite which possess multiple capabilities. Mr. Johnson obtained a quoted mission description for this system from the "Yuzhnoye" Scientific-Production Association (NPO) which states the following:

- all-weather monitoring of ice conditions;
- all-weather monitoring of wind-induced seaway, storm and cyclone regions (mesoscale convective cells of active power interchange of ocean and atmosphere, atmospheric precipitation regions);
- all-weather monitoring of flood regions;
- radar and optical monitoring of dynamic phenomena on the ocean surface (pollution zones, internal waves, upwelling, etc.). (11:60)

Okean-0 satellites are launched from Plesetsk on SL-14 boosters into an inclined orbit of 82.5 degrees with a period of 98 minutes and an apogee of 665 km and a perigee of 635 km.

4.3.7.4 Almaz. The Almaz was launched in 1987 into low earth orbit with a mean altitude of 255 km, inclined at 71.93 degrees, and with a period of 89.55 minutes. It was launched from Tyuratam on a SL-13 booster. The Almaz produced commercially available remote sensing products from a number of scientific disciplines. The next scheduled launch will be sometime this year.

4.3.7.5 Prognoz. The Prognoz is a geostationary remote sensing platform used to monitor the Earth's natural resources, oceans, and atmosphere. Launched from Tyuratam on a SL-12 booster, the satellite was placed into a geostationary orbit, inclined at 1.26 degrees, and located above the equator at 12 degrees east.

Table 11. Remote Sensing Satellite Orbits

PROGRAM	APOGEE (km)	PERIGEE (km)	INCL (deg)	PERIOD (min)
Resurs-0	660	617	97.97	97.49
Okean-0	665	635	83.00	98.00
Almaz	259	245	71.93	89.55
Prognoz	35,800	35,782	1.26	1436.34

Table 12. Remote Sensing Satellite Launch Sites and Boosters

PROGRAM	LAUNCH SITE	BOOSTER
Resurs-0	TT	SL-3
Okean-0	PL	SL-14
Almaz	TT	SL-13
Prognoz	TT	SL-12

4.3.8 *Scientific Satellites.* The Soviet Scientific satellite program covers the disciplines of atmospheric, geophysics, materials science, biology, and astrophysics. In the history of the Soviet scientific satellite program a wide variety of orbits have been employed, however, over the last five years, only six of these have been used for the missions listed in Table 13. The *Photon* series is used to conduct microgravity experiments in the area of materials processing and biotechnology. Yearly launches are planned through the early 1990s. The *Bion* is a short duration mission used to investigate biological effects of motion sickness, reproduction and regeneration, immunology, and readaptation to a normal gravity environment. Future Bion missions are being planned. In 1986, Kosmos 1809 was launched to study the ionosphere (14:37). Two satellites, *Prognoz 10* and *Aktiviny*, were launched to study the sun and the magnetosphere. The latest scientific mission launched in 1989 was the *Granat* astrophysical observatory. Over a dozen scientific satellite programs are planned for the next ten years and into the next century. These program will investigate the following:

- issues pertaining to the origin and evolution of the universe.
- radiation detection
- solar wind and the Earth's magnetosphere
- solar observations and phenomena
- mapping of the celestial sphere for astronomical, astronautical, and geophysical studies

- use of a gamma ray telescope
- use of small scale laboratories to study plasma structures in the near-Earth environment
- universal background radiation
- the structure and dynamics of the upper atmosphere

Table 13. Scientific Satellite Orbits

PROGRAM	APOGEE (km)	PERIGEE (km)	INCL (deg)	PERIOD (min)
Photon	380	216	62.8	90.5
Bion	267	207	82.3	89.7
Kosmos 1809	966	945	82.5	104.2
Prognoz 10	200,320	421	65.0	5785.0
Aktiviny	2,493	500	82.6	115.9
Granat	202,480	1,760	51.9	5928.0

Table 14. Scientific Satellite Launch Sites and Boosters

PROGRAM	LAUNCH SITE	BOOSTER
Photon	PL	SL-4
Bion	PL	SL-4
Kosmos 1809	PL	SL-14
Prognoz 10	TT	SL-6
Aktiviny	PL	SL-14
Granat	TT	SL-12

4.3.9 Early Warning Satellite Orbits. The Soviet early warning satellites support their missile attack warning system. These satellites are placed in orbits similar to the Molniya communication satellites and are launched on the same SL-6

booster. However, early warning satellites have only been launched from Plesetsk. The Soviets early warning constellation of nine satellites in individual planes spaced 40 degrees apart ensures constant observation of the western and central United States.

Table 15. Early Warning Satellite Orbit

PROGRAM	APOGEE (km)	PERIGEE (km)	INCL (deg)	PERIOD (min)	CONSTELLATION
Early Warn	40,000	400	63	718	9 planes spaced 40° 1 satellite per plane

Table 16. Early Warning Satellite Launch Site and Booster

PROGRAM	LAUNCH SITE	BOOSTER
Early Warn	PL	SL-6

4.3.10 Electronic Intelligence Satellites. The Soviet ELINT satellite is a military surveillance satellite used to collect strategic and tactical data in the non-visible portion of the electromagnetic spectrum. The Soviets have two constellations of ELINT satellites. The lower altitude constellation contains one satellite in each of the six planes that are spaced 60 degrees apart, while the higher constellation possess one satellite in each plane spaced 45 degrees apart. The lower altitude ELINT satellites are launched from Plesetsk on SL-14 boosters into inclined orbits of 83 degrees with a period of 98 minutes and an apogee and perigee of 665 and 635 km, respectively. The higher altitude satellites are now launched from Tyuratam on SL-16 boosters. Previous launches were on SL-12 boosters and, in 1985, two launches on an unidentifiable booster. The orbits are inclined 71 degrees with a period of 102 minutes and apogee and perigee of 855 and 850 km, respectively.

Table 17. Electronic Intelligence Satellite Orbits

PROGRAM	APOGEE (km)	PERIGEE (km)	INCL (deg)	PERIOD (min)	CONSTELLATION
ELINT 1	665	635	65	98	6 planes spaced 60° 1 satellite per plane
ELINT 2	855	850	71	102	4 planes spaced 45° 1 satellite per plane

Table 18. ELINT Satellite Launch Sites and Boosters

PROGRAM	LAUNCH SITE	BOOSTER
ELINT 1	TT	SL-6
ELINT 2	PL	SL-16

4.3.11 *Ocean Surveillance Satellites.* Due to the significant size of Western naval forces, the Soviet Union has placed heavy emphasis on the maintenance of an operational ocean surveillance satellite system.

The objectives of the Soviet ocean reconnaissance network are to detect, identify, and track U.S. and Allied naval forces and to relay this information in realtime directly to Soviet naval and air elements. (6:53)

The Soviet ocean surveillance network is composed of two satellite systems. The *Radar Ocean Reconnaissance Satellite* (RORSAT) system consists of one or two satellites in a single plane. The orbit is inclined 65 degrees with a period of 90 minutes, an apogee of 270 km, and a perigee of 250 km. The *ELINT Ocean Reconnaissance Satellite* (EORSAT) system is in a constellation of two planes spaced 172 degrees apart with one to three satellites per plane. The orbit is higher than that of the RORSAT with an apogee of 420 km and a perigee of 405 km, inclined at 65 degrees with a period of 93 minutes. Both systems are launched from Tyuratam on SL-11 boosters.

Table 19. Ocean Reconnaissance Satellite Orbits

PROGRAM	APOGEE (km)	PERIGEE (km)	INCL (deg)	PERIOD (min)	CONSTELLATION
RORSAT	270	250	65	90	1 plane 1-2 satellites
EORSAT	405	420	65	93	2 planes spaced 172° 1-3 satellites per plane

Table 20. Ocean Reconnaissance Satellite Launch Sites and Boosters

PROGRAM	LAUNCH SITE	BOOSTER
RORSAT	TT	SL-11
EORSAT	TT	SL-11

4.3.12 Minor Military Satellites. This category of Soviet satellite missions was created by the late Dr. Charles Sheldon II working in the Library of Congress who was instrumental in providing Soviet space assessments to the U.S. Senate. The category includes satellites systems which the Soviets have not released in any scientific literature and do not fit in any other categories. Speculative missions associated with these satellites, as reported by the U.S. Senate Committee on Commerce, Science, and Transportation and described by Mr. Johnson, include radar calibration, measurement of atmospheric density, and spacecraft technology experimentation (11:86). Two possible categories have been established. One group of minor military satellites uses an orbit with a period between 102-109 minutes, an apogee of 1600-200 km, and a perigee of 300-400 km. The second group is characterized by a circular orbit with a period of 94.5 minutes. Soviet minor military satellites have been launched into inclinations of 50.7, 65.8, 74.0, and 83 degrees. The boosters used on these systems include the SL-8 and the SL-14 launched from Plesetsk and Tyuratam.

Table 21. Minor Military Satellite Orbits

PERIOD (min)	INCLINATION (degrees)
102-109	50.7, 65.8, 83.0
94.5	50.7, 65.8, 74.0

Table 22. Minor Military Launch Sites and Boosters

PROGRAM	LAUNCH SITE	BOOSTER
102-109 min periods	PL	SL-8
94.5 min period	PL, KY	SL-8, SL-14

4.3.13 *Co-orbital Anti-Satellite.* For the past seven years, the Soviets have not conducted any overt anti-satellite tests in space. The Soviet's co-orbital anti-satellite (ASAT) was first tested in 1967 and the last operation was conducted in 1982. Mr. Johnson states that in *The Soviet Space Challenge*, the U.S. Department of Defense believes this system is capable of reaching targets at an altitude of 5000 km and is able to conduct multiple launches each day (11:89). With the aid of radar and optical sensors, the co-orbital ASAT moves close to the target and then explodes, destroying the target with the multi-pellet blast (18:21). Soviet co-orbital ASATs have been launched from Tyuratam on SL-11 boosters, however the Soviets could employ SL-14 boosters from Plesetsk, which would increase target opportunities and decrease response times.

Table 23. Co-orbital ASAT Launch Site and Booster

PROGRAM	LAUNCH SITE	BOOSTER
ASAT	TT	SL-11
(possible)	PL	SL-14

4.3.14 Manned Space Program

4.3.14.1 *Mir*. The Soviet manned space program centers on the space station *Mir*, which is the operational replacement of the *Salyut* space station which was abandoned in 1986. Launched in 1986 from Tyuratam on a SL-13 booster, the *Mir* space station conducts missions in the areas of visual reconnaissance, astrophysical and biological research, monitoring Earth resources, and materials processing.

4.3.14.2 *Kvant*. Attachments to *Mir* were accomplished with the *Kvant* modules 1 and 2 launched from Tyuratam on the SL-13 booster. The first *Kvant*, module, launched in 1987, contained international scientific instruments and support equipment for *Mir*. The module was an astrophysical lab which also contained a multi-spectral Earth resources camera and a payload which had six control moment gyros called *Gyrodins* (13:85). Due to the success of these gyros in space station stabilization and propellant cost savings, the *Kvant* 2 module was also equipped with moment gyros and 32 small orientation engines. *Kvant* 2 also had support equipment to improve normal space station operations. Additional equipment included water, oxygen, sanitation, power, and environmental monitoring systems. The module also contained an array of instruments for geophysical and astrophysical experimentation.

4.3.14.3 *Soyuz*. The *Soyuz* program is the backbone of the Soviet manned program and provides manned flights to the *Mir* space station. The latest version of this spacecraft is the *Soyuz-TM*, which possesses an improved navigation and rendezvous system, for docking with *Mir*, and a new communication system (14:61). The *Soyuz-TM* is boosted into orbit from Tyuratam on the SL-4 booster. Its specific missions are to advance Soviet space flight technology (maneuvering and docking), engineering and biological research, and conduct operations in the construction of the manned space platform (18:62).

4.3.14.4 *Progress*. Unmanned resupply missions to the Soviet space station are flown by the *Progress* cargo ship, which is also launched from Tyuratam on SL-4 boosters. *Progress* is very similar in design to the Soyuz spacecraft, however, *Progress* weighs significantly less since there are no solar panels, heat shielding, or an emergency escape system (18:54). This reduction in required equipment, allows for increased cargo capacity. But the most important improvement in the *Progress* design was the inclusion of a returnable capsule with a capacity of 150 kg. This improvement alleviates the requirement for a Soyuz mission to deliver materials from Mir back to Earth.

4.3.14.5 *Buran*. In 1988, the Soviets launched its version of the U.S. Space Shuttle, the *Buran*. Despite the successful flight of the Soviet unmanned shuttle, no *Buran* flights occurred in 1989 because of technical difficulties, lack of political support, and an acceptable justification for its mission. According to *Komsomolskaya Pravda*, as described by Mr. Johnson, *Buran* was grounded for economic reasons (11:111). Current plans call for one flight per year from 1991 to 2000, even though the Soviets are capable of launching once a month. The next *Buran* mission will also be unmanned and Mr. Johnson states that *TASS* reported that the flight will dock with Mir, presenting the option of returning cosmonauts to Earth via the shuttle.

4.3.15 *Planetary Satellites*.

4.3.15.1 *The Moon*. The year 1989 marked the 30th anniversary of the Soviet lunar exploration program which began with *Luna 1*, *Luna 2*, and *Luna 3*. The last *Luna* flight was in 1976 and next *Luna* flight is scheduled for 1992. Mr. Johnson quotes Yu. I. Zaytsev who stated that the mission of the proposed flight is as follows:

Table 24. Manned Program Orbits

PROGRAM	APOGEE (km)	PERIGEE (km)	INCL (deg)	PERIOD (min)
Mir	395	392	51.62	92.42
Kvant	*	*	*	*
Soyuz	*	*	*	*
Prognoz	*	*	*	*
Parameters based on Progress M-2 mission on 20 Dec 89				
* dependent upon Mir orbit				

Table 25. Manned Program Launch Site and Boosters

PROGRAM	LAUNCH SITE	BOOSTER
Mir	TT	SL-13
Kvant	TT	SL-13
Soyuz	TT	SL-4
Progress	TT	SL-4
Buran	TT	SL-17

to compile detailed video atlases, morphological and geological maps, maps of the chemical composition and radioactivity of the surface, and maps of magnetic, gravitational and thermal fields. (11:115)

4.3.15.2 Venus. During 1961 and 1984, the Soviets launched 30 probes toward Venus. However, the next proposed Venus mission is not scheduled until 1998 and calls for firing a number of surface penetrators at the planet.

4.3.15.3 Mars. For the next couple of decades, the primary focus of the Soviet planetary exploration program will center on the planet Mars, with an ultimate goal of a manned landing and return to Earth. During 1988, the Soviets launched Mars probes *Phobos 1* and *Phobos 2*. According to *Krasnaya Zvezda*, as mentioned by Mr. Johnson, *Phobos 1* was lost due to an attitude control failure. In orbit around Mars, *Phobos 2* began rotating which degraded solar array performance, and thus power, causing the vehicle to reach critical temperature. The next Soviet Mars mission is planned for 1994 and calls for the deployment of balloons, from entry modules, to analyze the meteorological and surface condition of the planet. A 1996 mission calls for the return of samples from the Mars moon, *Phobos*, followed by a 1998 mission to conduct soil analyses of the planet through the use of rovers.

4.3.16 Launch Vehicle Testing. A series of four launch vehicle tests for the SL-16 booster began in October 1986 and was completed in August 1987 (13:13). ELINT payloads have been successfully launched with this booster, however, its more important role is to serve as a strap-on booster for the SL-17 booster, the *Energia*.

4.4 Summary

The size and diversity of the Soviet space program is impressive. The Soviet knowledge and application of space systems span a broad spectrum. In reviewing the mission descriptions, it is possible to divide the Soviet space platforms into two

categories, based upon their relation to the military. Table 26 lists the categories for Military and Non-military Soviet satellite systems.

Table 26. Military versus Non-military Soviet Satellite Systems

MILITARY	NON-MILITARY
Photographic	Communication
Communication	- Molniya
- Low alt	- Ekran
- Raduga	- Gorizont
Navigation	- Kosmos
Meteorology	Remote Sensing
Geodetic	Scientific
Early Warn	Manned
ELINT	Planetary
Ocean Recon	
Minor Mil	
ASAT	
LV Tests	

V. Influence Diagram Model

5.1 Introduction

This chapter will present the influence diagram model developed from the data discussed earlier. First, an overview of the basic elements and operations of influence diagrams will be presented. Next, will be a description of the prediction variables used in the model, succeeded by a an analysis of the probabilistic relationships that exist among these variables. The chapter will conclude with the actual influence diagram model. The graphical representation will illustrate the variables and their relationships while, in the next chapter, the underlying data structure of the diagram which will show the actual calculated probabilistic relationships.

5.2 Influence Diagram Overview

This section provides a more specific description of influence diagrams than was presented in the literature review. Illustrative examples of solving influence diagrams will be presented in the discussion of discrete and continuous variables. As mentioned in the literature review, the basic elements of an influence diagram include *chance nodes*, *decision nodes*, *value nodes*, and *deterministic nodes*. Figure 1 shows how these nodes are represented graphically.

- The *chance node*, a circle, represents a random variable in the influence diagram. An arc from one chance node into another chance node indicates a *probabilistic dependence* conditioned on the sucessor node by the predecessor node and the absence of an arc between two chance nodes indicates a *conditional independence* (Figure 2). The underlying data structure of the chance node contains the representative probability distribution.
- The *decision node*, a square, can represent any decision in the model and contains the various alternatives involved in a particular decision. An arc into

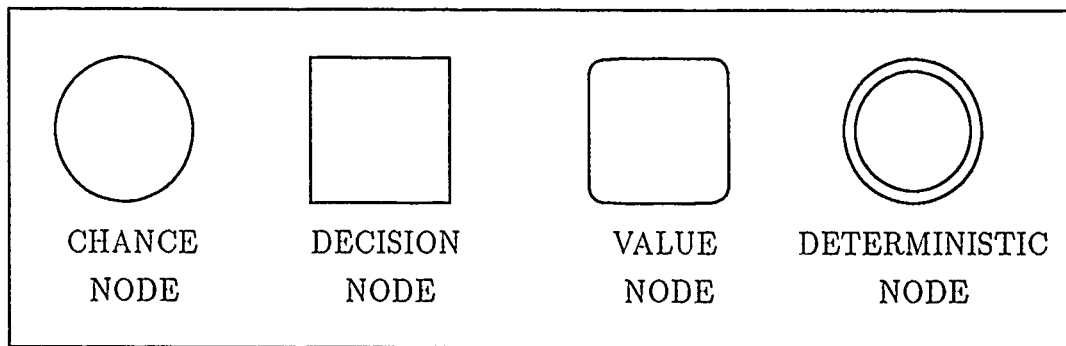


Figure 1. Graphic Representation of Nodes

a decision node represents information available at the time of the decision (Figure 2).

- The *value node*, a rounded rectangle, represents the value of the model based upon the resulting probabilistic outcomes and decisions made in the model. The data structure of the value node includes a utility table which is based upon the model's preceding probabilities and the decisions made.
- The *deterministic node*, a double circle, represents a variable whose value becomes known once the outcomes of the preceding conditional variables are revealed.

Certain transformations, or reductions, of the influence diagram can be accomplished which still preserve the informational value of the underlying data structure. These transformations involve the removal of nodes from the diagram until only a value node remains. This process reveals the maximum value of the model represented and the optimal decision policies to undertake based upon the maximization of utility. The four basic operations of node removal include:

- **Barren Node Removal:** A barren node is defined as any node (except the value node) which has no successors. A barren node may

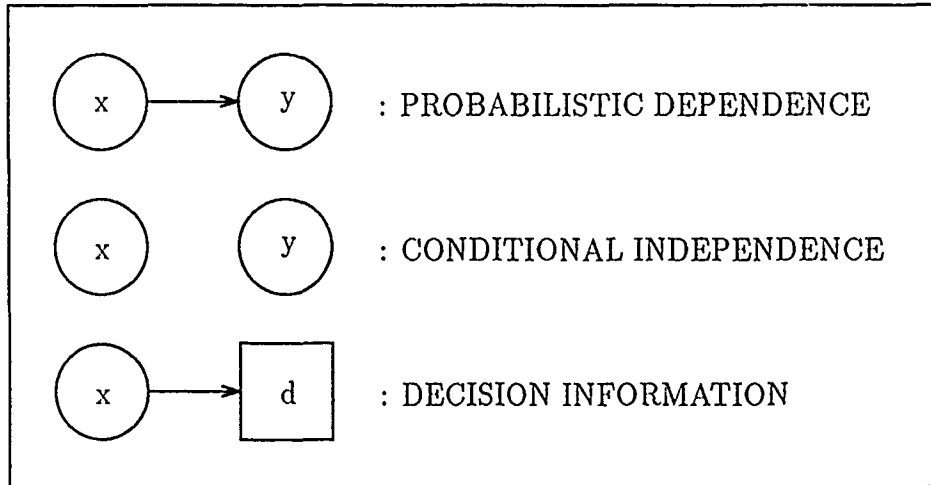


Figure 2. Nodal Relationships

simply be removed from the diagram without affecting the problem outcome because the fact that it has no successors implies that it has no influence either directly or indirectly on the value node. In order to solve a diagram any barren nodes created must be removed after each reduction operation.

- **Expectation:** If a chance node directly precedes the value node and nothing else in a properly formed diagram it may be removed by conditional expectation. Expectation removes a node by summing the product of probabilities for the chance node's outcomes with the value node's value resulting from each outcome. A side effect is that all direct predecessors of the removed node are now direct predecessors of the value node.
- **Maximization:** If a decision node is a direct predecessor of the value node and all other direct predecessors of the value node are also informational predecessors of the decision node then the decision node may be removed by maximizing the expected value of the value function conditioned on the other predecessors of the value node. A side effect of maximization is that some of the informational predecessors of the decision node may become barren nodes since the value node does not inherit any new predecessors from this reduction.
- **Arc Reversal:** If an arc exists between two chance nodes and there is no other path between them then the arc may be reversed by ap-

plying Bayes' Rule to the two node's probability distributions. A side effect is that the two nodes involved inherit each others predecessors, possibly creating new arcs in the diagram. This operation is often needed when solving influence diagrams to allow a chance node to be removed by expectation. (3:13)

Graphic representations of these operations are summarized in Figure 3. Specific examples will be provided in the next chapter.

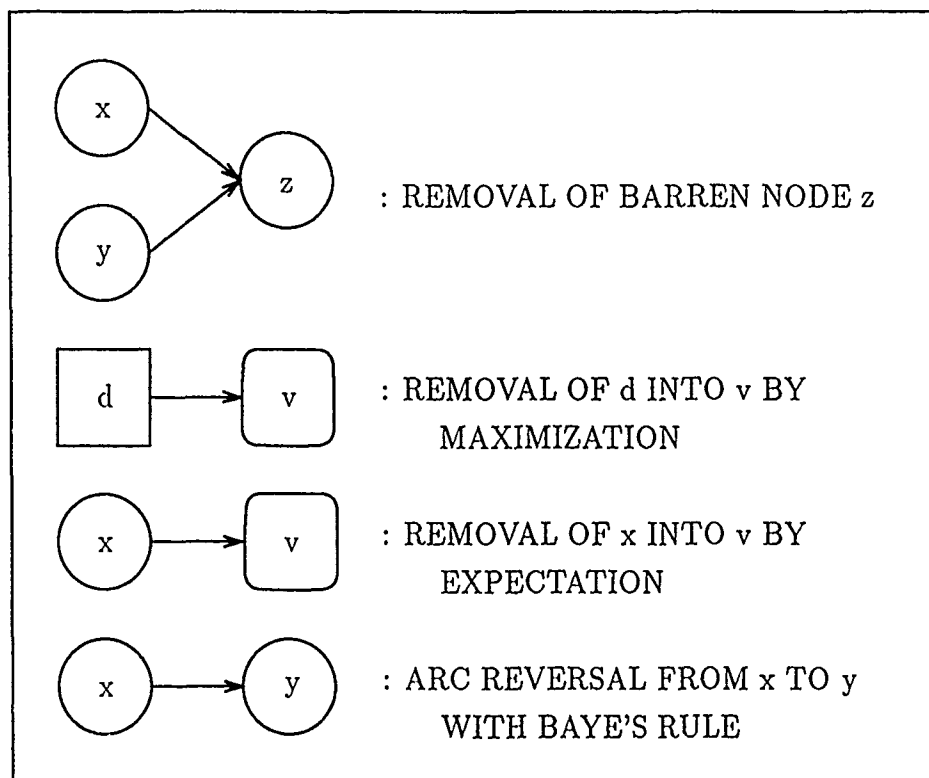


Figure 3. Node Reductions

5.3 Predictive Variables

The predictive variables available for use in the influence diagramming model were limited by the data availability from unclassified sources. The parameters used are as follows:

- **Launch Site** - The Soviets have three operational launch sites for placing satellite payloads into orbit: Plesetsk, Tyuratam, and Kapustin Yar.
- **Booster** - The Soviets currently possess 10 operational launch vehicles to support their space program: SL- 3, SL-4, SL-6, SL-8, SL-11, Sl-12, SL-13, Sl-14, Sl-16, and SL- 17.
- **Inclination** - The angle measured from the equatorial plane to the orbital plane. Inclination is measured in degrees. The inclination is 0 or 180 degrees for an equatorial orbit, 90 degrees for a polar orbit, less than 90 degrees for a satellite with an eastward (prograde) motion around the earth, and greater than 90 degrees for a satellite with a westward (retrograde) motion.
- **Apogee** - The distance, measured in kilometers, from earth to the farthest point in the satellite's orbit.
- **Perigee** - The distance, measure in kilometers, from earth to the closest point in the satellite's orbit.
- **Number of Payloads** - This variable represents the number of payloads that were deployed from the launch in question.
- **Argument of Perigee** - The angle measured in the orbital plane from the ascending node (equatorial crossing from south to north) to perigee. This angle is undefined for a circular orbit, since there is no perigee. The angle is also undefined for an equatorial orbit, since there is no ascending node.
- **Geosynchronous Position** - The position on the equator measured to the east from the Greenwich meridian.

The eccentricity and the period of the orbit are not used as predictive variables in the influence diagram model since their influences are captured by the values of apogee and perigee. The eccentricity and period are deterministic from apogee and perigee and could be represented in the model as deterministic nodes. However,

these deterministic nodes would not provide any additional information towards the prediction of the satellite mission. Also, the launch time was not used as a predictive variable since the launch time is dependent upon the day of the year the launch occurred and the database used in this research does not sufficiently represent all the possible outcomes.

5.4 Probabilistic Relationships

This section will describe how each of the variables influence each other and contribute towards the prediction of the satellite mission. Expert opinion was consulted to define these relationships. Interviews were conducted with Major T.S. Kelso (16), Mr. Nicholas L. Johnson (9), and Captain Ken Norton (21). Major Kelso has experience in the Satellite Control Network, specifically in the activation of the Consolidated Space Operations Center in Colorado Springs, CO and also in satellite operations at the Air Force Satellite Control Facility in Sunnyvale, CA. Mr. Nicholas Johnson, as mentioned earlier, is the Advisory Scientist for Teledyne Brown Engineering and has devoted a number of years to the study of the Soviet Space program. Captain Ken Norton spent five years in the Cheyenne Mountain Complex in support of the Space Surveillance Center. The collective inputs of these experts contributed to the formulation of the following relationships:

- *Mission and Number of Payloads* - The number of payloads deployed, with the satellite in question, helps to predict the mission outcomes when multiple payloads are involved. Table 27 shows these various combinations.
- *Mission and Inclination* - The inclination of the orbit helps determine the Earth coverage of the satellite. The inclination specifies the greatest northern and southern latitudes that the satellite's orbit will trace on the ground of the Earth. For example, low altitude communication satellites have highly inclined orbits to provide coverage to the northern territories of the Soviet Union.

Table 27. Multiple Payload Mission Combinations

Number of Payloads	Mission Combination
2	(2) Science
3	(3) Navigation
3	(2) Navigation (1) Geodetic
3	(2) Science (1) Photographic
6	(6) Low Altitude Communications
8	(8) Low Altitude Communications

- *Mission and Apogee* - The apogee plays an important role in determining the satellites field of view of the Earth and the eccentricity and period of the orbit. These characteristics are essential in the planning of a satellites orbit for a specific mission. For example, a Molniya orbit is characterized by a high eccentricity (high apogee and low perigee) which allows for an extended period of time and coverage over a specific geographic area.
- *Mission and Perigee* - The perigee is also used in determining the orbit's eccentricity and period.
- *Mission and Argument of Perigee* - The argument of perigee will be used in the model only to distinguish between the Molniya communication and the early warning satellites since the orbit of these two missions possess an identical apogee, perigee, and inclination. The argument of perigee determines where the satellite will geographically *hover*. The Molniya orbits have argument of perigee values in the range of 280 to 288 degrees, while the early warning satellites are from 316 to 318 degrees (9).
- *Mission and Geosynchronous Position* - The position on the equator of a geosynchronous satellite will be used to discriminate among the military and civilian communication missions and, also, the remote sensing missions.

- *Inclination and Launch Site* - Due to range safety concerns, such as launching over populated areas and predicting the impact of first and second stage boosters, launch sites are restricted from launching directly into certain inclinations. Therefore, the desired inclination influences the particular launch site to be used. For example, inclinations greater than 90 degrees can only be launched from Tyuratam (11:9).
- *Apogee and Booster* - A booster must have enough lifting capability in order to place a payload into a specific apogee. The desired mission apogee influences the choice of boosters.
- *Booster and Site* - Once a booster is selected, the choice of launch sites might be limited, since certain boosters can only be launched from certain sites. For example, launch sites have a limited number of pads which are designed to specifically support certain boosters. Additionally, a launch site might possess booster specific ground equipment, support facilities, and personnel.

5.5 Influence Diagram Model

With the predictive variables and their probabilistic relations defined, it is possible to construct the influence diagram. The software programs, *AFIDS* and *InDia*, allow construction of the diagram by choosing the type of node, labeling the node, specifying the number of outcomes, and positioning the node on the screen. Once the nodes have all been entered, the conditioning arcs must be drawn between the nodes to represent the probabilistic relationships. Next, the probability distributions are entered for each node. The user's manual for *AFIDS* explains the specific procedures required to construct the influence diagram (3) and *InDia* contains an online help directory. Figure 4 shows the influence diagram model.

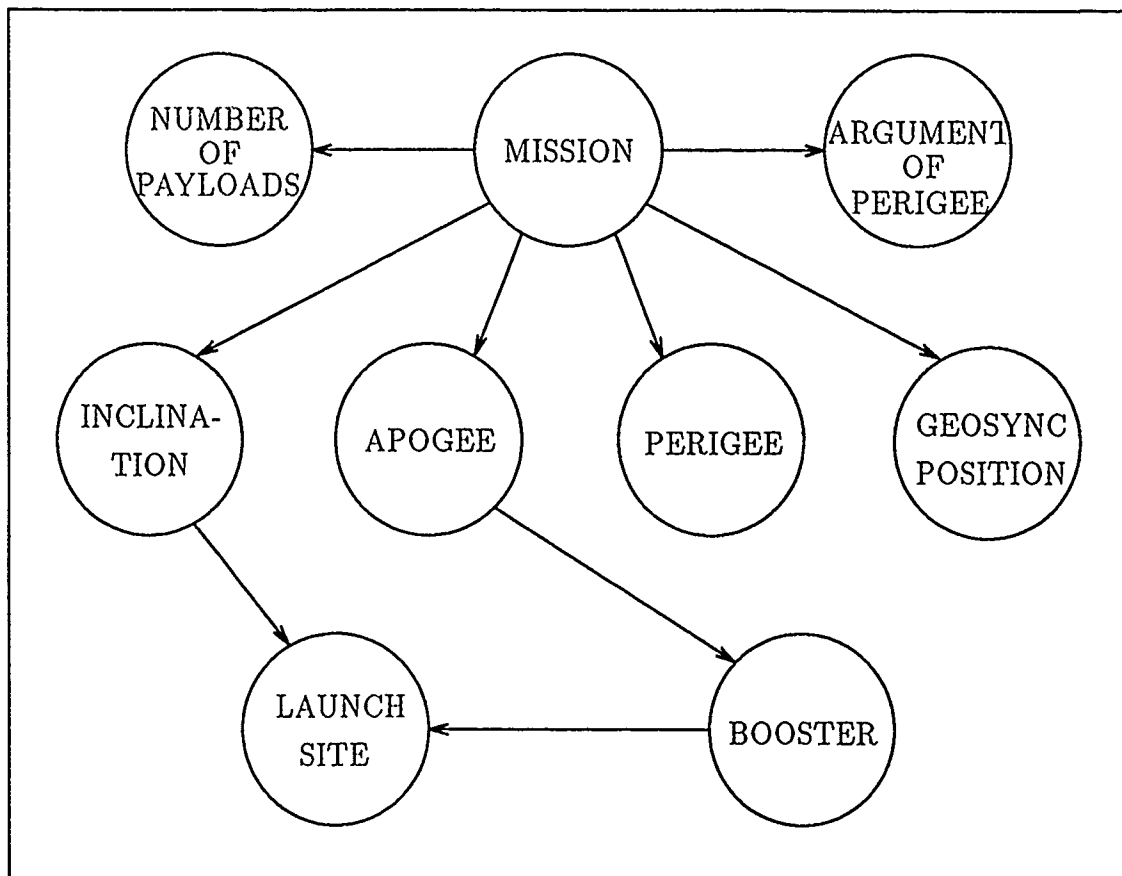


Figure 4. Influence Diagram Model

5.6 *Summary*

The overview presented in the chapter introduces the basic elements and operations of an influence diagram. The predictive variables and their interrelationships were defined which allowed for the construction of the influence diagram. With the construction of the graphical model complete, the next step required is to calculate the probability distributions represented by the arcs in the influence diagram.

VI. Discrete and Continuous Variable Analysis

6.1 Introduction

Each of the model variables, presented in the last chapter, represent large masses of ungrouped data. To formulate probability distributions, this data must be grouped into classes. How these classes are determined depends on the nature of the data. Classifications that can be expressed as qualitative classes or categories are often referred to as *discrete variables*. If the range of the data for a random variable is either finite or countably infinite, then the variable is discrete. In contrast, *continuous variables* can assume any value in a given range or interval. This chapter will describe how influence diagrams manipulate discrete and continuous variables and also discuss the implications of using both types of variables in a single influence diagram model. Illustrative examples will be presented to demonstrate the data manipulation procedures conducted by the influence diagramming software. Finally, the calculated probability distributions will be presented.

6.2 Discrete Variables

The influence diagram model consists of five discrete variables. Table 28 lists these variables along with their discrete classes. The geosynchronous position was assumed to be discrete due to the limited number of available positions on the equator and the registration requirements for such orbits. The following example demonstrates how influence diagrams manipulate discrete variables in the solution process.

One of the possible discrete variables that could be applied to determining the mission of Soviet satellite might be *launch site*. The relationship representing the probability that a certain satellite mission is launched from a particular Soviet site is represented by the simple influence diagram shown in Figure 5. This figure

Table 28. Discrete Model Variables and Their Classes

Mission	Launch Site	Booster	No. of Payloads	Geosync Position
Photographic	Tyuratam	SL-3	1	35
Communication	Plesetsk	SL-4	2	40
Military Comm	Kapustin Yar	SL-6	3	45
Navigation		SL-8	6	49
Meteorology		SL-11	8	53
Geodetic		SL-12		70
Early Warning		SL-13		80
ELINT		SL-14		85
Ocean Recon		SL-16		90
Minor Military		SL-17		95
ASAT				96.5
LV Test				99
Remote Sensing				103
Scientific				128
Manned				140
Planetary				190
Unknown				335
				336
				346
				349

represents the *influence* that the mission has on the location of the Soviet launch. This diagram is the top level of the influence diagram. The secondary level includes the data and the probabilistic relationships between the variables. The *chance node*, labeled **MISSION**, possesses the *prior* probability distribution for specific missions [$P(\text{Mission})$]. These prior probabilities, for the example, are listed in Table 29. Prior probabilities are those probabilities established before obtaining additional information from other variables in the model. Prior probability formulation could be based upon historical data, intelligence information, the world situation, the age of particular Soviet space platforms, etc. For example, if it is known that a critical Soviet communication satellite has malfunctioned, then there would be a high probability that the Soviets will launch a replacement satellite.

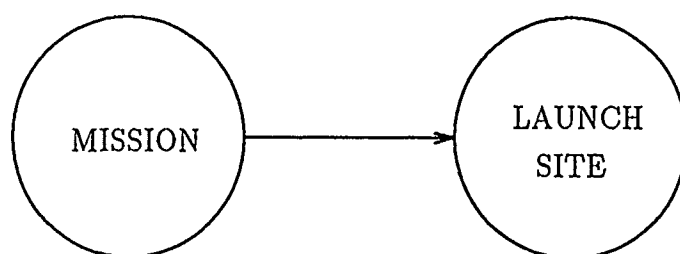


Figure 5. Influence Diagram Example

Table 29. Prior Probabilities

MISSION	PROBABILITY
Communication	0.70
Photographic	0.20
Navigation	0.10

The chance node labeled **LAUNCH SITE** possesses the *likelihood probability distribution* that shows, for a given mission, the probability that it was launched from a particular site [$P(\text{Launch Site}/\text{Mission})$]. The formulation of this probability

distribution is based upon historical data. For the example problem, the likelihood distribution is listed in Table 30.

Table 30. Likelihood Probabilities

MISSION	LAUNCH SITE		
	TT	PL	KY
Communication	0.80	0.20	0.00
Photographic	0.40	0.55	0.05
Navigation	0.50	0.40	0.10

The example influence diagram could also be represented by the probability tree in Figure 6. However, this probability tree only represents two variables with three classes for each variable. This demonstrates how an influence diagram simplifies the graphical representation of the relationships between variables. The complexity of the probability tree significantly increases as more variables and more classes are added. If our actual model was constructed into a probability tree, it would have to contain each predictive variable and every possible combination of outcomes. Influence diagramming provides a more efficient means of graphically representing the model and manipulating the probability distributions.

The graphical representations and the data presented thus far in this discrete example would be a compilation of information available prior to a Soviet launch. When a Soviet launch does occur, the relationship of interest would then be as represented in Figure 7. This figure represents how the information of **LAUNCH SITE** influences the mission probability. If it is known where the launch occurred, this information would help to determine the distribution representing the possible missions associated with the launch. Therefore, the direction of the arc in Figure 5 must be reversed as represented in Figure 7. When reversing an arc between two nodes, each node inherits the predecessors of each other. In the example, there are

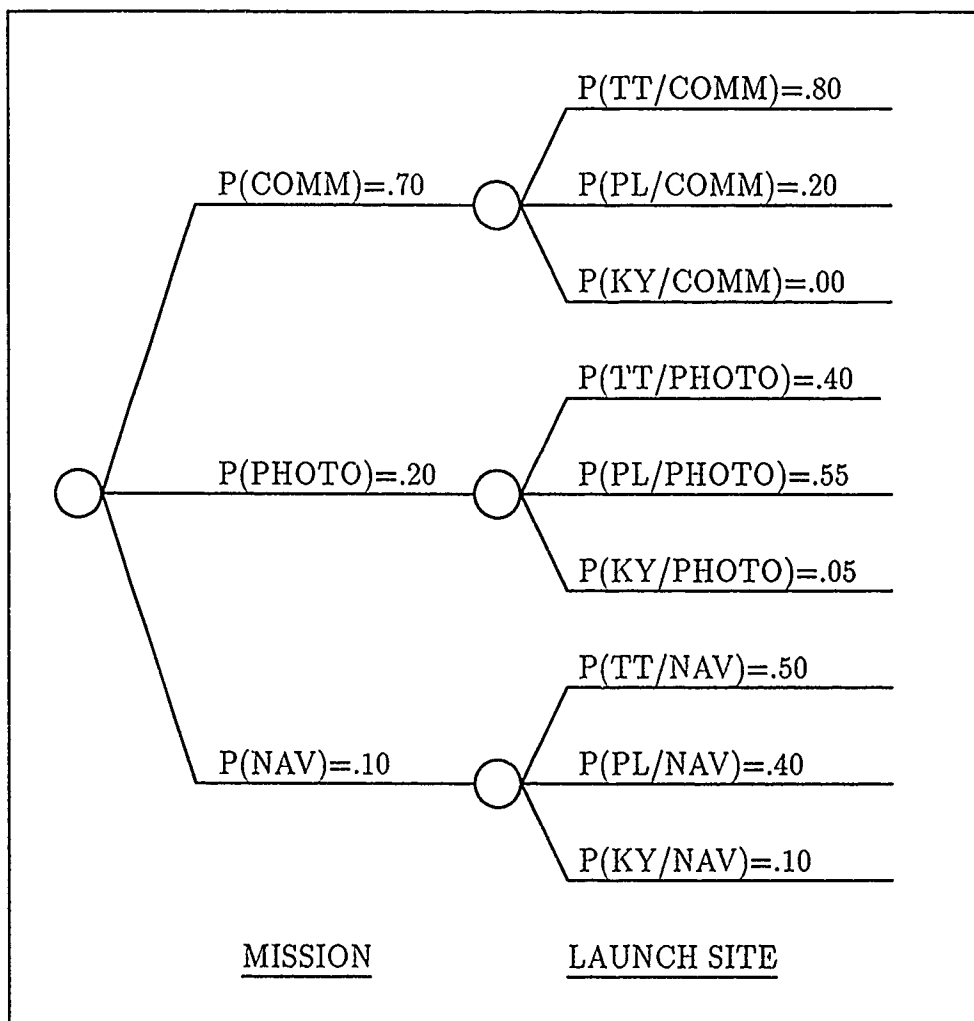


Figure 6. Probability Tree

only two nodes, so it is possible to simply reverse the arc. However, Figure 8 shows how new arcs can be created when reversing an arc between two nodes.

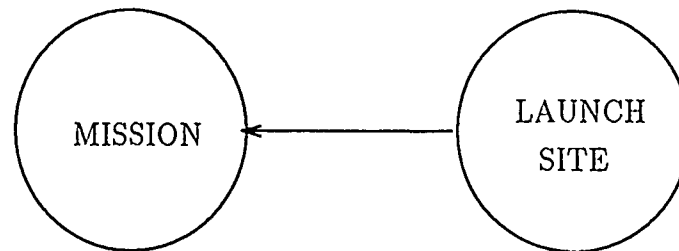


Figure 7. Arc Reversal

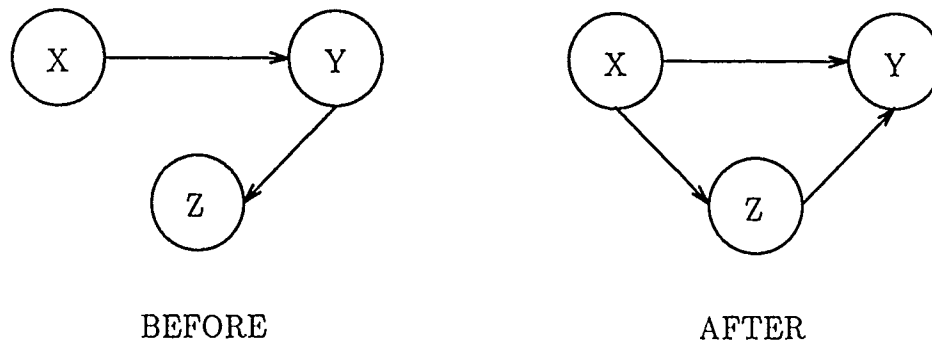


Figure 8. Arc Reversal Between Y and Z

Node X influences Node Y and Node Y influences Node Z. After reversing the arc between Node Y and Node Z, an arc is created from Node X to Node Z. Node Z inherited the predecessor, Node X from Node Y. The reversing of an arc affects the probability distributions of the second level of the influence diagram. The arc reversal between two chance nodes is accomplished by applying *Bayes' Theorem* (5:61):

$$P(A_k/B) = \frac{P(A_k \cap B)}{P(B)} = \frac{P(B/A_k)P(A_k)}{\sum_{i=1}^n P(B/A_i)P(A_i)}; k = 1, \dots, n$$

Multiplying the *prior* probabilities (Table 29), $P(\text{Mission})$, and the *likelihood* probabilities (Table 30), $P(\text{Launch Site}/\text{Mission})$, gives the *joint* distribution (Table 31). This distribution represents the influence of the prior probabilities onto the likelihood probabilities. Summing the columns of the *joint* distribution gives the *preposterior* probabilities for each launch site (Table 32), $P(\text{Launch Site})$.

Table 31. Joint Probabilities

MISSION	LAUNCH SITE		
	TT	PL	KY
Communication	$(0.70) \times (0.80) = 0.56$	$(0.70) \times (0.20) = 0.14$	$(0.70) \times (0.00) = 0.00$
Photographic	$(0.20) \times (0.40) = 0.08$	$(0.20) \times (0.55) = 0.11$	$(0.20) \times (0.05) = 0.01$
Navigation	$(0.10) \times (0.50) = 0.05$	$(0.10) \times (0.40) = 0.04$	$(0.10) \times (0.10) = 0.01$

Table 32. Preposterior Probabilities

LAUNCH SITE	PROBABILITY
TT	0.69
PL	0.29
KY	0.02

The new probability tree is shown in Figure 9. The tree has been “reversed” and now shows how the information of the **LAUNCH SITE** influences the outcome of the **MISSION**.

The *preposterior* probability distribution is the new distribution for the chance node **LAUNCH SITE** in Figure 7. Dividing the *joint* distribution by the *preposterior* probabilities yields the *posterior* distribution (Table 33), $P(\text{Mission}/\text{Launch Site})$, which is now the secondary level of the chance node labeled **MISSION**.

The posterior probability distribution is a revision of the prior probability distribution based upon additional information. Once the site of a particular launch is

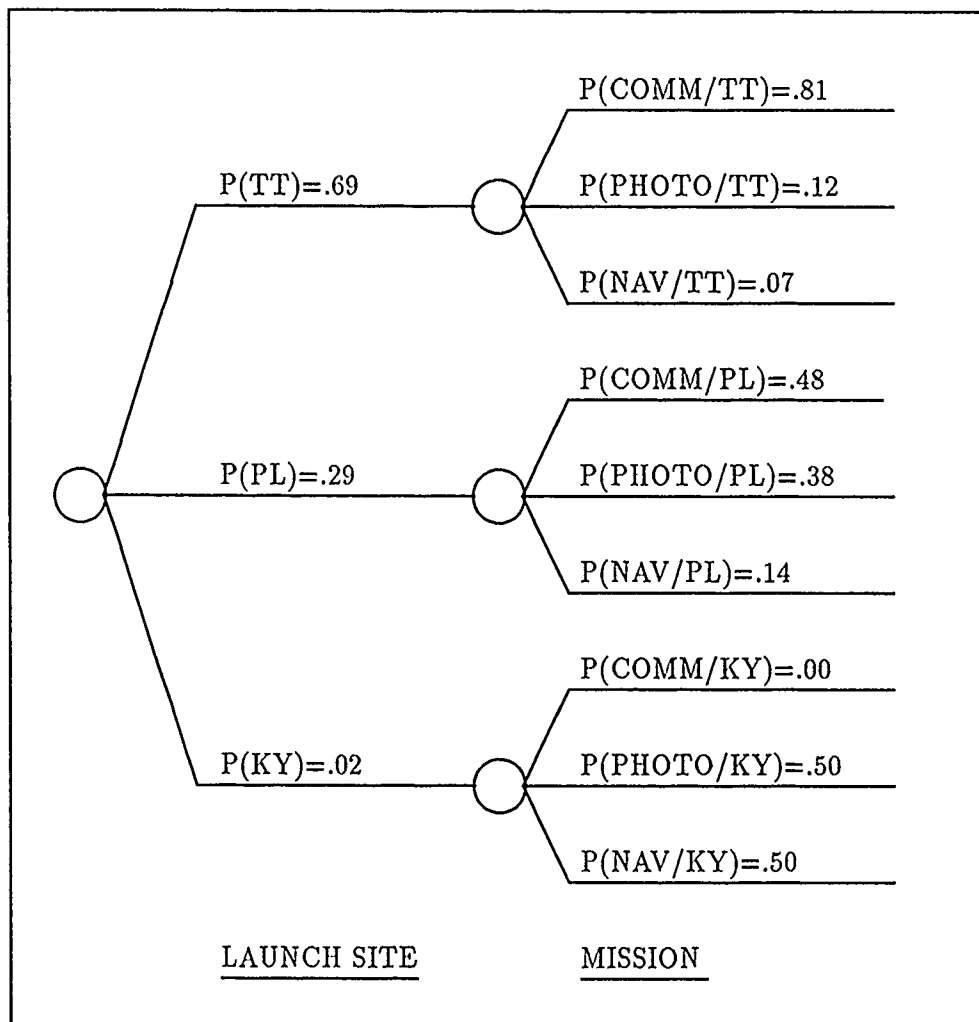


Figure 9. Probability Tree After Arc Reversal

Table 33. Posterior Probabilities

MISSION	LAUNCH SITE		
	TT	PL	KY
Communication	$(0.56)/(0.69) = 0.81$	$(0.14)/(0.29) = 0.48$	$(0.00)/(0.02) = 0.00$
Photographic	$(0.08)/(0.69) = 0.12$	$(0.11)/(0.29) = 0.38$	$(0.01)/(0.02) = 0.50$
Navigation	$(0.05)/(0.69) = 0.07$	$(0.04)/(0.29) = 0.14$	$(0.01)/(0.02) = 0.50$

known, Table 33 is able to provide the probabilities for the possible missions associated with that launch. In our example, if the launch site is known to be *Tyuratam* (TT), then the possible missions associated with the launch are Communication, Photographic Reconnaissance, and Navigation with probabilities of 0.81, 0.12, and 0.07, respectively. Table 34 shows how the new information of knowing the actual launch site has affected the probability outcome for the possible satellite missions. The new distribution incorporates this known information into the prediction model.

Table 34. Mission Probabilities Comparison

MISSION	Prior To Launch	With Launch Site Info
Communication	0.70	0.81
Photographic	0.20	0.12
Navigation	0.10	0.07

The above example demonstrates how known information from a single variable (launch site) is incorporated into the model. More information should then be obtained from additional predictive variables. The basic purpose of attempting to incorporate more evidence from additional predictive variables is to reduce the uncertainty, thereby, improving the predictive power of the model.

6.3 Continuous Variables

Now that discrete variables have been discussed, the attention focuses on the use of continuous variables. In the Soviet mission prediction model there are four continuous variables that are considered. These variables and their ranges are listed in Table 35. For discrete variables, determination of the probability distribution classes is rather trivial since the classes are determined by the unique possible outcomes of the variable (Launch Site: Tyuratam, Plesetsk, and Kapustin Yar). However, for continuous variables, defining the probability classes is significantly more difficult since the variables can assume any value in a specified range (Inclination: any value

between 0 and 180 degrees). Before these class intervals can be determined, the probability density function of the continuous variable must first be defined.

Table 35. Continuous Model Variables

Variable	Range
Apogee	170 to 202,500 km
Perigee	160 to 35,800 km
Inclination	0 to 100 degrees
Argument of Perigee	0 to 360 degrees

6.3.1 Probability Density Function. The definition of a probability density function is as follows:

Let X be a continuous random variable. Then a **probability distribution** or **probability density function** (p.d.f.) of X is a function $f(x)$ such that for any two numbers a and b with $a \leq b$,

$$P(a \leq X \leq b) = \int_a^b f(x)dx$$

That is, the probability that X takes on a value in the interval $[a, b]$ is the area under the graph of the density function.

In order that $f(x)$ be a legitimate p.d.f., it must satisfy the two conditions

1. $f(x) \geq 0$ for all x
2. $\int_{-\infty}^{\infty} f(x)dx = \text{area under the entire graph of } f(x) = 1$ (5:125)

This functional form of the probability distribution is not easy to derive or ascertain from the observational data. This subsection will discuss various methods of approximating the probability density function empirically from the historical satellite data.

6.3.1.1 *Graphical Methods.* Graphs provide a useful means of selecting a probability distribution to describe data. **Frequency Diagrams** of the observed data can be plotted and then visually compared to a known density function. Table 36 lists the sample inclination data for Soviet Early Warning satellites. Using the statistical software package, *STATGRAPHICS*, a frequency tabulation table can be generated as in Table 37. Plotting the frequency histogram for this inclination data yields Figure 10. Examination of the graph reveals that the data is approximately *normally* distributed.

Table 36. Sample Inclination Data

Early Warning Satellite Inclination Data			
Data Number	Degrees	Data Number	Degrees
1	62.76	13	62.92
2	62.83	14	62.93
3	62.85	15	62.94
4	62.85	16	62.97
5	62.86	17	62.98
6	62.87	18	62.98
7	62.90	19	62.99
8	62.90	20	62.99
9	62.90	21	63.03
10	62.91	22	63.04
11	62.91	23	63.05
12	62.91		

Probability Plotting is another graphical method which determines whether the data conforms to a hypothesized distribution based on a subjective visual examination of the data. This technique requires the use of special graph paper, known as *probability paper*, that is designed specifically for the hypothesized distribution. To plot the observed data on this paper, the following must be accomplished:

Table 37. Frequency Tabulation

Class	Lower Limit	Upper Limit	Midpoint	Freq.	Rel. Freq.	Cum. Freq	Cum Rel Freq
at or below	62.70	62.70		0	.0000	00	0.0000
1	62.70	62.76	62.73	0	.0000	00	0.0000
2	62.76	62.81	62.79	1	.0435	01	0.0435
3	62.81	62.87	62.84	5	.2174	06	0.2609
4	62.87	62.93	62.90	7	.3043	13	0.5652
5	62.93	62.99	62.96	5	.2174	18	0.7826
6	62.99	63.04	63.01	4	.1739	22	0.9565
7	63.04	63.10	63.07	1	.0435	23	1.0000
above	63.10			0	.0000	23	1.0000
Mean = 62.9248 Standard Deviation = .0719766 Median = 62.91							

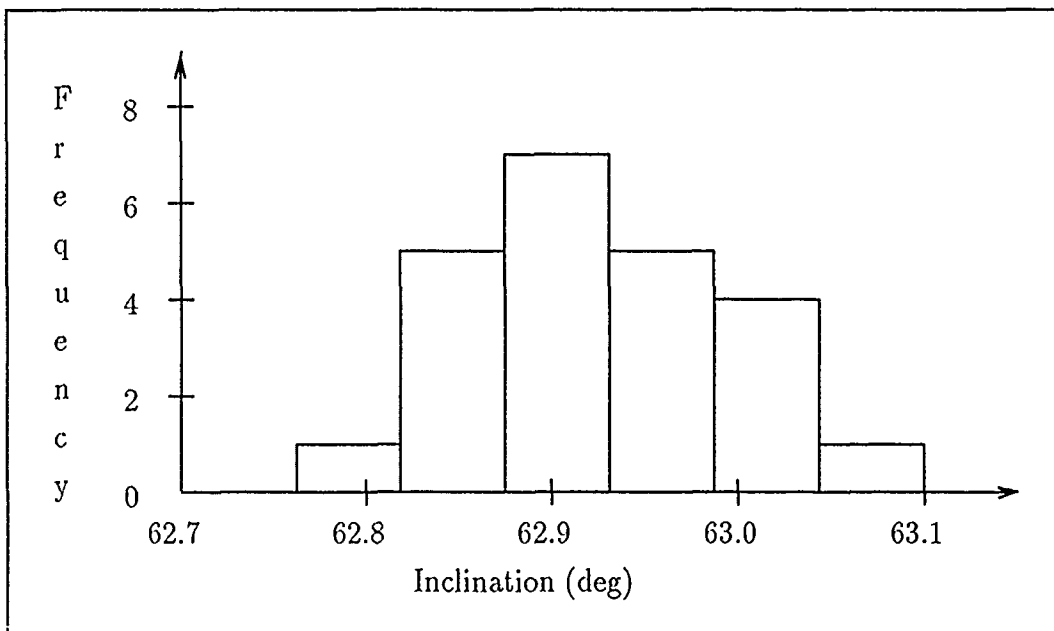


Figure 10. Example Frequency Histogram

If there are N observations x_1, x_2, \dots, x_N , the m th value among the N observations (arranged in increasing order) is plotted at the cumulative probability $m/(N + 1)$. (1:262)

If the hypothesized distribution adequately describes the data, the plotted points will fall approximately along a straight line; if the plotted points deviate significantly from a straight line, then the hypothesized model is not appropriate. Figure 11 shows the *STATGRAPHICS* generated normal probability plot for the early warning inclination data. Since the data points of the probability plot are approximately linear, without any significant deviations, it is possible to conclude that the data is *normally* distributed.

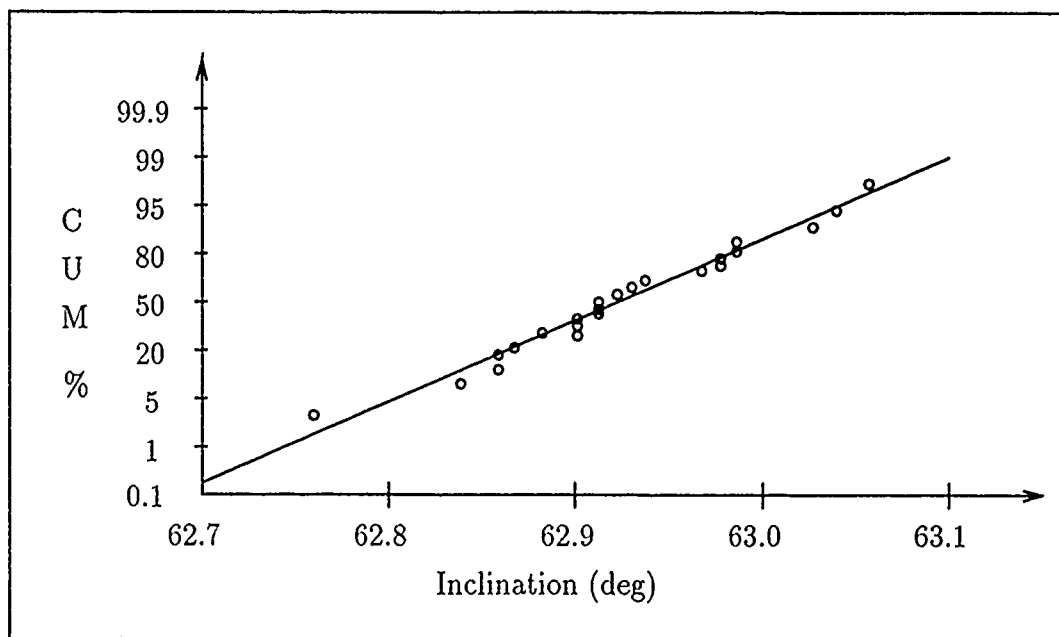


Figure 11. Normal Probability Plot

6.3.1.2 Statistical Methods. Using the above graphical methods to determine the probability density function is somewhat subjective to the examiner of the graph. Statistical methods can be applied to further support or deny the hypoth-

esized distribution for the observed data. These methods are known as “*goodness-of-fit*” tests.

One such procedure for testing the hypothesis of a specific distribution is the Chi-square (χ^2) test. The test procedure consists of obtaining a random sample of size n of the random variable X , whose probability density function is unknown. These n observations are grouped into a frequency histogram, having k intervals. Letting n_i be the observed frequency in the i th class interval. From the hypothesized probability distribution, the expected frequency is computed for each interval, denoted by e_i . The test statistic is (1:274):

$$\chi_o^2 = \sum_{i=1}^k \frac{(n_i - e_i)^2}{e_i}$$

χ_o^2 approximately follows the chi-square distribution (χ_f^2) with ($f = k - p - 1$) degrees of freedom, where p represents the number of parameters of the hypothesized distribution estimated by sample statistics. This approximation improves as n increases. If $\chi_o^2 > \chi_{\alpha, f}^2$, then the hypothesis that X conforms to the hypothesized distribution is rejected. Table 38 shows the *Chi-square goodness-of-fit* test for the example inclination data. Testing with a significance level of .05, yields the conclusion that the data is normally distributed with a mean of 62.9248 and a standard deviation of .0719766.

Another statistical method used for distribution validation is the Kolmogorov-Smirnov (K-S) test. In the K-S goodness-of-fit test, the cumulative frequency of the observed data is compared to the distribution function of the hypothesized distribution. The sample data of size n is sorted in ascending order and a step-wise

Table 38. Chi-Square Test for Relative Goodness-of-fit

Lower Limit	Upper Limit	Observed Frequency	Expected Frequency	Chi-square
below	62.81	1	1.14	0.017
62.81	62.87	5	4.01	0.244
62.87	62.93	7	6.99	0.000
62.93	62.99	5	6.98	0.562
62.99	63.04	4	2.74	0.579
63.04	above	1	1.14	0.017
				—
				$\chi_o^2 = 1.419$
$\chi_{.05,6-2-1}^2 = 7.815 < \chi_o^2 \rightarrow$ Distribution is Normal				

cumulative frequency function is developed as follows:

$$S_n(x) = \begin{cases} 0 & x < x_1 \\ \frac{k}{n} & x_k \leq x < x_{k+1} \\ 1 & x \geq x_n \end{cases}$$

Using the above function (1:278), $S_n(x)$ is plotted along with the hypothesized distribution function, $F(x)$, as shown in Figure 12. To test the goodness-of-fit of the data to the hypothesized distribution, the maximum difference between $S_n(x)$ and $F(x)$, over the entire range of the observational data, must be calculated. This measure of discrepancy between the observed data and the hypothesized distribution is denoted by (17:199):

$$D_n = \sup_x |F(x) - S_n(x)|$$

This maximum difference, D_n , is then compared to a critical value D_n^α , where n is the sample size and α is the significance level. If $D_n < D_n^\alpha$, then the observed data fits the hypothesized distribution. The K-S test was run on the early warning

inclination data using *STATGRAPHICS* and obtained a D_n value of 0.104343, which is less than the $D_{23}^{.05}$ critical value of .278 (1:385). Therefore, the normal model $N(62.9248, 0.0719766)$ is verified at the .05 significance level.

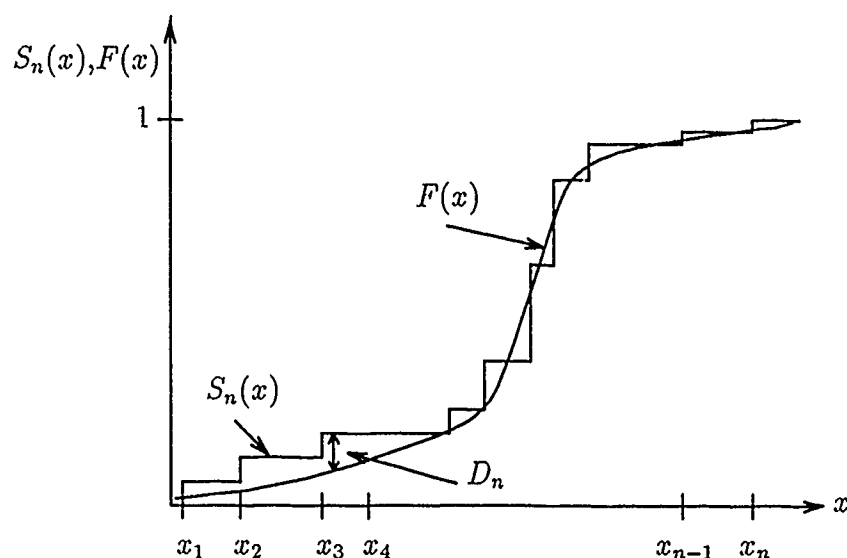


Figure 12. Graph for Kolmogorov-Smirnov Test(1:278)

6.3.2 Determination of Variable Classes. Once the probability density functions for the continuous variable have been defined, it is possible to graph them along the range of values for that specific variable to identify conflicts when determining classes for that variable. An example of a section from the *apogee* range might look like Figure 13.

Having the defined the probability density functions for the continuous variable allows for the probability calculation of any defined interval in the range of the data. The next step, then, is to define the intervals or classes for each continuous variable in the model. Figure 13 showed that the probability density functions may overlap. This causes a problem when attempting to determine where the mission class intervals are to be drawn. If the parameter of interest falls into this region of overlap, it causes a conflict in determining the mission of the unknown satellite.

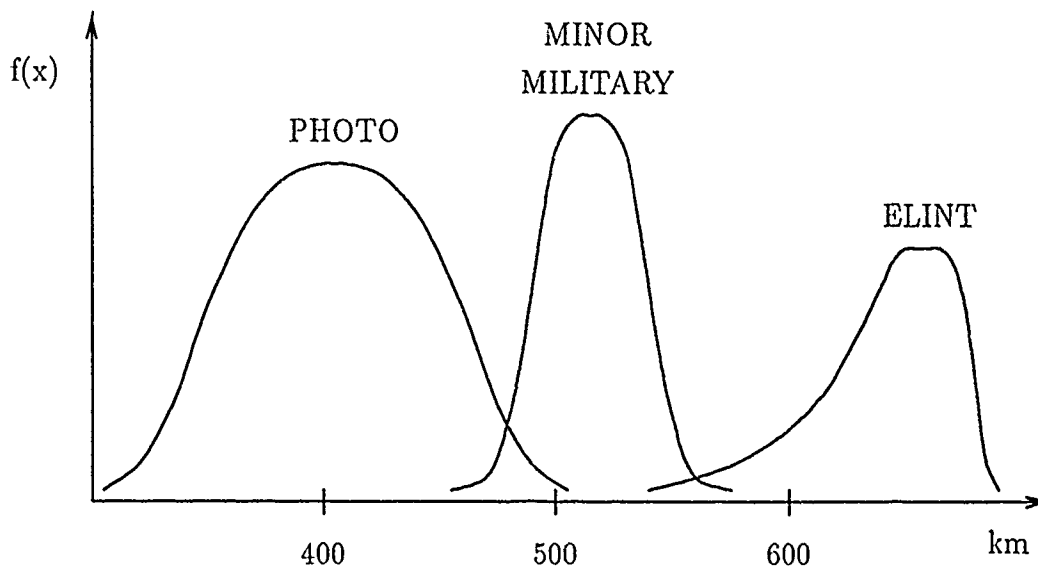


Figure 13. Example Section of PDF Graph for Apogee

Figure 14 shows a possible region of conflict between two missions in the *perigee* range (distributions are approximated to allow description of the process).

Due to the overlapping density functions in Figure 14, there is no clear-cut value of perigee that can be used to distinguish the *early warning* satellites from the *civilian communication* satellites. Therefore, a method must be formulated to resolve such conflicts in a manner optimal to the user of the model. *Hypothesis testing* addresses the important question of how to choose among alternative propositions or courses of action, while controlling and minimizing the risks of wrong decisions.

Consider the process of determining a satellite's mission from a particular value of the parameter *perigee*, which is in the region of conflict in Figure 14. Assuming that in this particular range of perigee values, the only possible missions are early warning and civilian communication, the decision maker must decide which is the correct mission. Using the language of hypothesis testing, the null hypothesis being tested, H_0 , is that the satellite has an early warning mission. The alternative hypothesis, H_a , is that the satellite is not early warning and is used for civilian

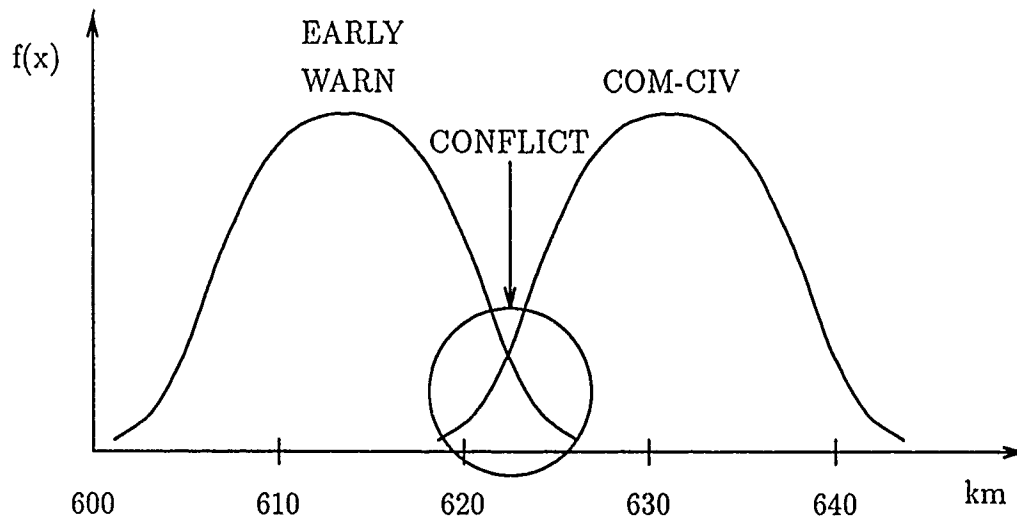


Figure 14. Critical Area in Overlapping Density Functions

communication. After receiving the information on the perigee of the satellite, if the decision maker concludes that the satellite is early warning, then the null hypothesis is accepted. On the other hand, if the decision maker concludes that the satellite is not early warning, then the null hypothesis is rejected. Analyzing the situation that results, after the decision maker has reached a conclusion, reveals that four possibilities exist. The first two possibilities pertain to the case in which the null hypothesis H_o is true, and the second two pertain to the case in which the null hypothesis is false. The possibilities are as follows:

1. The satellite is early warning (H_o is true), and the decision maker concludes early warning (H_o is accepted); hence, the correct decision has been made.
2. The satellite is early warning (H_o is true), but the decision maker concludes not early warning (H_o is rejected); hence, the wrong decision has been made.
3. The satellite is not early warning (H_o is false), and the decision maker concludes not early warning (H_o is rejected); hence, the correct decision has been made.

4. The satellite is not early warning (H_o is false), but the decision maker concludes early warning (H_o is accepted); hence, the wrong decision has been made.

In cases 1 and 3, the decision maker reaches the correct decision; in cases 2 and 4, an error is made. In hypothesis testing, two types of errors are possible:

A **type I error** consists of rejecting the null hypothesis H_o when it is true.

A **type II error** involves not rejecting H_o when H_o is false. (5:280)

Note that under the current legal system, a person is assumed innocent (H_o : Person is innocent) until proven guilty (H_a : Person is guilty). In this situation, a *Type I error* is considered far more serious than a *Type II error*; it is worse to convict an innocent man than to let a guilty one go free. If the null hypothesis had been that the defendant was guilty, then the meaning of the Type I and Type II errors would have been reversed. In the statistical formulation of the hypotheses, how the decision maker chooses to exercise control over the two types of errors is a basic guide in stating the hypotheses to be treated. Controlling these errors will now be discussed. The cases for the early warning versus civilian communication example are summarized in Table 39.

Table 39. Type I and Type II Errors

Action Concerning Hypothesis H_o	State of Nature	
	H_o is True (early warning)	H_o is False (civilian comm)
Accept H_o	Correct Decision	Type II Error
Reject H_o	Type I Error	Correct Decision

Figure 15 shows the areas of Type I and Type II errors for the example hypothesis test, if the class division, or *critical value*, is made at a perigee equal to 623 km.

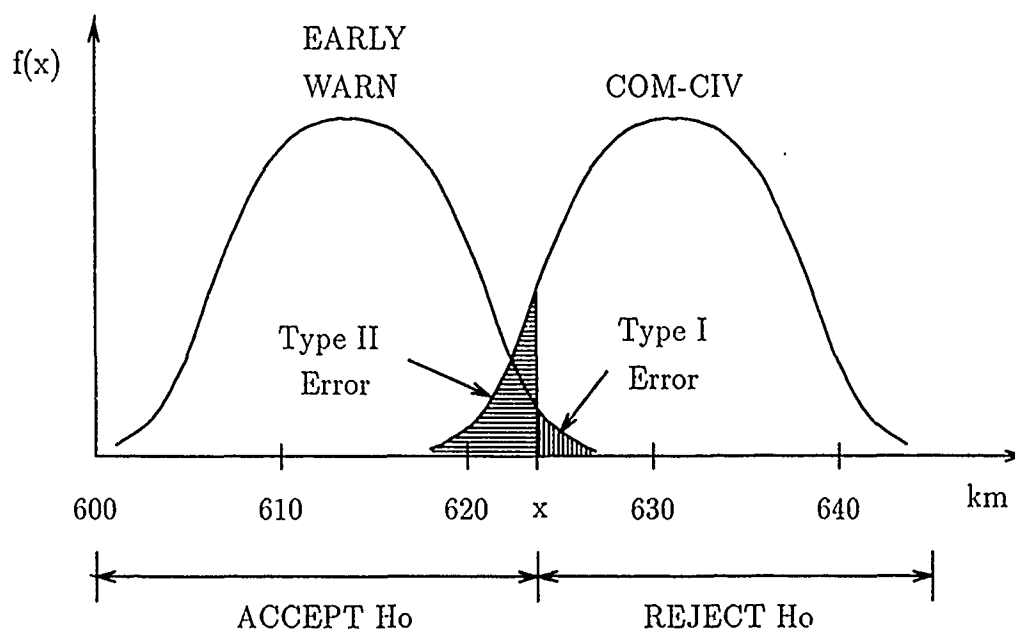


Figure 15. Type I and Type II Errors

Since the probability density functions of perigee for both missions are known, it is possible to calculate the areas representing the Type I and Type II errors of the hypothesis. For example, if the early warning-perigee probability density function is normally distributed with a mean $\bar{X} = 614$ and a standard deviation $\sigma = 5$, then the probability of a Type I error is calculated as follows (5:283):

$$\alpha = P(\text{type I error}) = P(H_0 \text{ is rejected when sat is early warn})$$

$$\alpha = P(\bar{X} \geq 623 \text{ when } \bar{X} \sim \text{normal with } \mu_{\bar{X}} = 614, \sigma_{\bar{X}} = 5)$$

$$\alpha = 1 - \Phi\left(\frac{623-614}{5}\right) = 1 - \Phi(1.8) = .0359$$

Correspondingly, if the probability density function for the perigee of civilian communication satellites is normally distributed with a mean $\bar{X} = 632$ and a standard

deviation $\sigma = 5$, then the probability of a Type II error is calculated as follows (5:283):

$$\beta = P(\text{type II error}) = P(H_o \text{ is accepted when sat is com-civ})$$

$$\beta = P(\bar{X} < 623 \text{ when } \bar{X} \sim \text{normal with } \mu_{\bar{X}} = 632, \sigma_{\bar{X}} = 5)$$

$$\beta = \Phi\left(\frac{623-632}{5}\right) = \Phi(-1.8) = .0359$$

The above calculations show the probability of a Type I and Type II error when the critical value of perigee was equal to 623 km. Table 40 shows how the Type I and Type II errors vary when the critical value is adjusted.

Table 40. Error Effects From Critical Value Adjustment

Critical Value	Type I Error	Type II Error
621	0.0808	0.0139
622	0.0548	0.0228
623	0.0359	0.0359
624	0.0228	0.0548
625	0.0139	0.0808
626	0.0008	0.1151
627	0.0005	0.1587

Figure 15 and Table 40 show that reducing the probability of one type of error increases the probability of the other type of error occurring, and vice versa. It is up to the decision maker to decide upon the degree of risk that is acceptable for each type of error. If the trade-off between the Type I and Type II errors is not acceptable, the decision maker also has a third alternative of not deciding between the alternatives. For example, once the minimum acceptable error of each type is independently determined, then the critical values of perigee can be assigned. Since there would be two independent critical values separating the mission classes, a third region is created in the conflict area. Figure 16 shows a Type I error of 0.0139, a Type II error of 0.0228, and a third region in which the decision maker does not

arrive at a conclusion. In this situation, a decision maker might choose to wait for further information before taking any action. This concept could be applied in the construction of an Anti-Satellite (ASAT) engagement decision model.

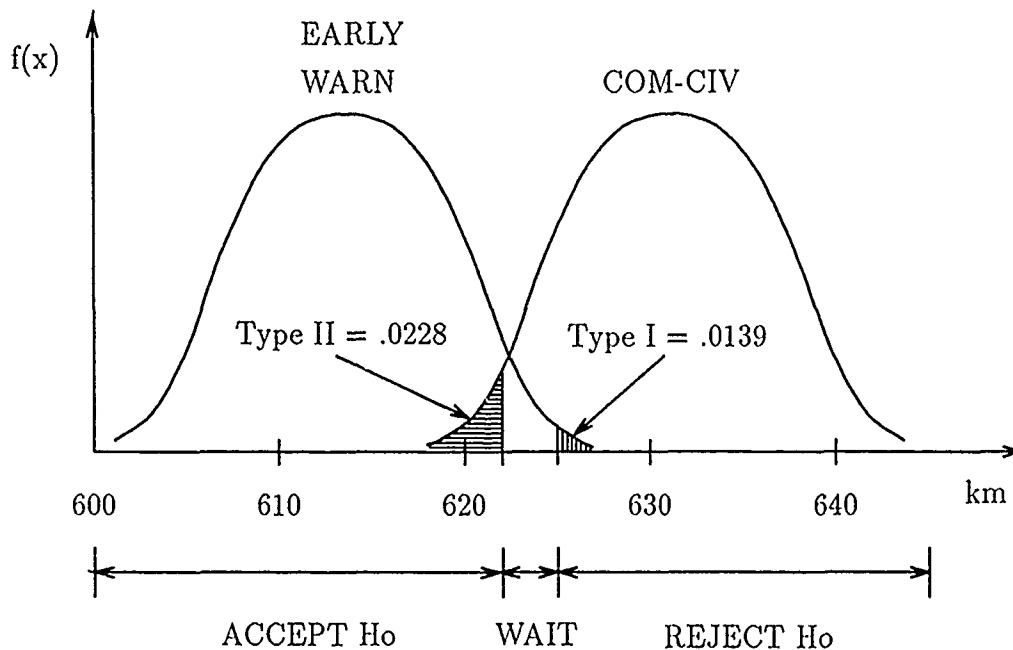


Figure 16. Third Decision Alternative

Suppose that the United States is in a hostile conflict with the Soviet Union and the U.S. must decide whether or not to launch an ASAT weapon at an unknown satellite. Based upon the perigee parameter, the decision maker will decide which course of action to take. Suppose the decision maker has chosen the critical perigee values in Figure 16 and decides that if the satellite perigee falls into the early warning range (600- 622), the ASAT will be fired, for a perigee value in the civilian communication range (625-645), the ASAT will not be fired, and for a perigee value in the uncertainty range (622-625), more information will be obtained before deciding whether to fire the ASAT. Table 41 summarizes these actions. The "Don't Shoot" option represents the decision maker's confidence that the satellite is not a possible ASAT target and additional information will not required or considered. However,

the "Wait" option represents the need for additional information before a decision can be reached.

Table 41. Possible Actions Based on Perigee Information

Perigee Range	Action To Be Taken
600 - 622 km	Shoot
622 - 625 km	Wait
625 - 645 km	Don't Shoot

The decision policy in Table 41 might not be the optimal decision policy. An influence diagram can help to determine the optimal policy. To incorporate this decision into an influence diagram, the decision maker assigns *utility values* to the all the possible outcomes. For example, firing an ASAT at an early warning satellite may be worth a utility value of 100 (mission is accomplished), not firing an ASAT at a early warning satellite may be worth zero (failure to accomplish mission), while firing an ASAT at a civilian communication satellite is worth 20 (ASAT resource expended, but Soviets lose some communication capability). The decision maker assign relative utility values to each possible outcome. The influence diagram representing this model is presented in Figure 17. The arc from the **PERIGEE** chance node to the decision node, **ASAT**, represents the information available at the time of the decision. The **MISSION** node contains the prior probabilities for each mission and the perigee node contains the likelihood probabilities of perigee conditioned on mission. The two arcs into the value node, **RESULTS**, shows that both the decision made and the probability of the mission affect the value of the outcome. The value node contains the utility values that the decision maker assigns to each possible outcome.

To illustrate the use of this model, assume the following information is entered into the data level of the influence diagram:

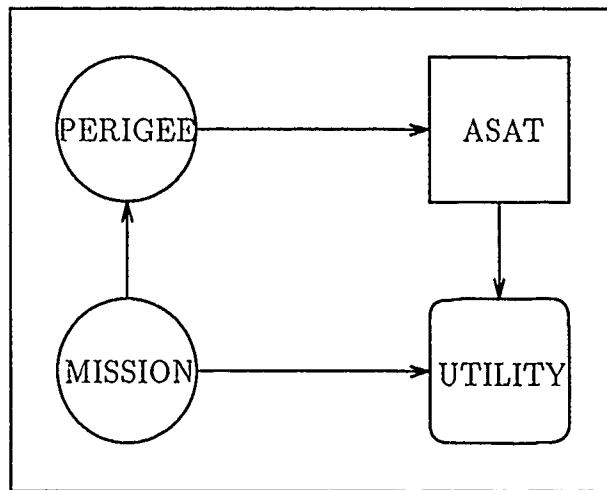


Figure 17. ASAT Decision Model Based on Perigee

- **MISSION NODE** - The chance node contains the prior probabilities for the early warning and civilian communication missions.

Table 42. Prior Probability of Mission

Early Warn	Comm-Civ
0.80	0.20

- **PERIGEE NODE** - This chance node contains the likelihood probabilities of perigee conditioned on mission.

Table 43. Likelihood Probabilities for Perigee

MISSION	PERIGEE RANGE		
	600-622 km	622-625 km	625-645 km
Early Warn	0.95	0.04	0.01
Comm-Civ	0.02	0.06	0.92

- **ASAT NODE** - This decision node contains the alternatives available to choose from conditioned on the outcome of the perigee.

Table 44. Decision Alternatives

DECISION
Shoot
Don't Shoot
Wait

- **Utility Node** - This value node contains the utility associated with each possible outcome. The value node is conditioned on the probability of the mission and the decision on the ASAT. Suppose that the utility values determined by the decision maker are as shown in Table 45.

Table 45. Value Table for Utility Node

MISSION	DECISION ALTERNATIVES		
	Shoot	Don't Shoot	Wait
Early Warn	100	0	20
Com-Civ	20	100	40

Solving the Model:

1. **Arc Reversal between MISSION and PERIGEE** - The first step required to solve the influence diagram is to reverse the arc from MISSION to PERIGEE using Bayes' Theorem. This allows the joint capture of the probability information from the prior and likelihood distributions. After the reversal, the PERIGEE node contains the preposterior distribution and the MISSION node contains the posterior distribution listed in Table 46.

Table 46. Posterior Distribution for Mission

PERIGEE RANGE	MISSION	
	Early Warn	Comm- Civ
600-622 km	0.995	0.005
622-625 km	0.727	0.273
625-645 km	0.042	0.958

2. **Removal of MISSION by Expectation** - The next step is to remove the chance node MISSION by Expectation. This process involves the summation of the product of the posterior probabilities of the MISSION outcomes with the UTILITY node's values for each outcome and yields Figure 18. This process is accomplished by multiplying the posterior probability matrix, Table 46, with the matrix formed by the utility values, Table 45, resulting in value table now conditioned on the outcome of perigee and the ASAT decision, Table 47.

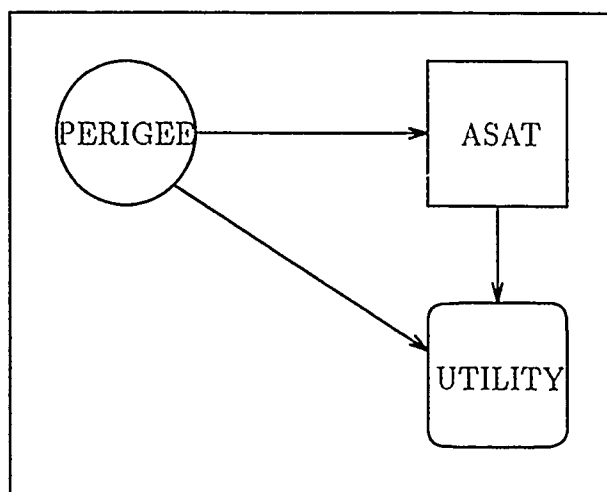


Figure 18. After Removal of MISSION by Expectation

3. **Removal of ASAT by Maximization** - Removal of the decision node ASAT is accomplished by maximizing the value of the utility node for each value of

Table 47. Value Table After MISSION Expectation

PERIGEE RANGE	DECISION ALTERNATIVE		
	Shoot	Don't Shoot	Wait
600-622 km	99.60	00.50	20.10
622-625 km	78.16	27.30	25.46
625-645 km	23.36	95.80	39.16

perigee. Therefore, UTILITY value node will contain the values in Table 48 and the decision node ASAT will contain the optimal decision policy conditioned on the outcome of perigee, Table 49. Therefore, once the actual measurement of perigee becomes available, the decision maker has the optimal policy. This shows that the model is lurking, like an expert system, waiting for the additional information required to choose the optimal decision.

Table 48. Maximum Values for UTILITY Conditioned on PERIGEE

PERIGEE RANGE	MAX UTILITY VALUE
600-622 km	99.6
622-625 km	78.16
625-645 km	95.8

Table 49. Optimal Decision Policy Conditioned on PERIGEE

PERIGEE RANGE	DECISION POLICY
600-622 km	Shoot
622-625 km	Shoot
625-645 km	Don't Shoot

As a result of removing the decision node by maximization, the influence diagram becomes Figure 19.

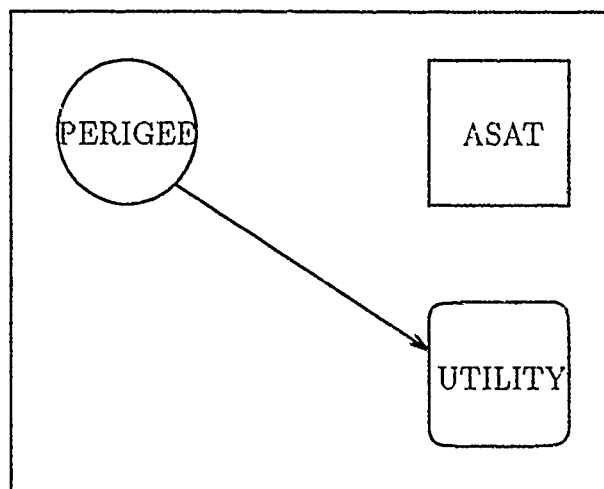


Figure 19. After Removal of ASAT by Maximization

The above decision model represents only a very small portion of a complete model. The complete range for parameter perigee would have to be analyzed and divided into classes and the model would also have to account for all possible Soviet satellite missions. The Soviet satellite prediction being developed in this research could be converted into an ASAT decision model by adding the decision node and the value node for utility. For example, if the optimal decision in the model was to wait for further information, the other predictive variables in the prediction model could provide this information needed by the decision maker. Development of a complete model would require an extensive analysis of the decision maker's thought process to determine the classes for each continuous variable (Acceptable Type I and Type II errors) and assigning utility values for each possible outcome. Additionally, a complete knowledge base on Soviet satellites would have to be compiled and incorporated into the model. Other nodes could also be included in the model. For example, a chance node could be added that contained the reliability of the

ASAT weapon. Once the information is properly organized and incorporated into the model, the decision maker will have an effective and easy to use decision tool.

6.4 *Discretizing Continuous Variables*

Currently, influence diagramming is limited to single *type* variable models. That is, the influence diagram must be constructed entirely of discrete variables or entirely of continuous Gaussian variables. A mix of discrete and continuous variables in a single model is not allowed. Moreover, the influence diagramming software programs used in this research are limited to discrete variables. Since the research model consists of both variable types, it is necessary to approximate a continuous variable as a discrete one. *Discretizing* allows the determination of probability classes for a continuous variable by choosing discrete values along the range of the continuous data and using these values to establish discrete class intervals. Each interval is then assigned a discrete number to represent that specific range of the interval. Once these "*discretized*" class intervals have been defined, it is possible to calculate the probabilities for each of the classes with the historical data. In this research model, the probability distributions functions were not calculated for each mission of each variable. Rather, once the variables were discretized, the probabilities for each interval were calculated based on the total number of observations within that interval.

6.4.1 Considerations. Discretizing allows the decision maker to strategically choose the class intervals which allow for quick identification of a satellite's mission. Partitioning of intervals can be accomplished by examining the mission profiles for each of the continuous variables and the range of the historical data versus mission. Expert knowledge is also essential to identify ranges in the data where mission distinctions can be made. For example, the *Ocean Reconnaissance* missions are placed in inclinations of approximately 65 degrees. If a class interval of 64.99 to 65.06 degrees was established for inclination, it would include only ocean reconnaissance missions.

However, when using this interval in the application of the predictive model, if the inclination of an unknown satellite had an inclination which fell into this interval, the model would identify it as an ocean reconnaissance satellite. However, *photo reconnaissance and navigation* satellites are often placed in inclinations of 64.8 and 64.9 degrees. If these satellites were placed in an orbit one-tenth of a degree above nominal or the measurement of inclination was off by the same amount, the model would still identify the mission as ocean reconnaissance. Therefore, in discretizing the class intervals for the continuous variables, the decision maker must be careful not to make the interval too small. The reverse is also true. If the interval is too wide and captures many different missions, then the class interval does not effectively distinguish among the missions. The decision maker must avoid choosing an interval which limits the possibilities for slight differences in the orbital parameter and does not contribute towards distinguishing mission types.

Another area of concern in discretizing a range of continuous variables involves those intervals in the range where no observations occur. For example, in the apogee range from 2,600 to 17,000 km there were no observed data points since the Soviets do not utilize orbits that occupy an apogee value in this range. Though such a range may not be currently used, there is always a possibility of future use by a newly developed orbit or the possibility of an anomalous orbit injection into such a range. Therefore, a decision maker must assess the various mission probabilities for these ranges. For example, higher probabilities might be assigned to missions with orbits above this range, since they may fail to reach the higher orbit and very small probability values might be assigned to the low orbit missions. Some type of *distance heuristic* may be applied which assigns higher probabilities to those missions closer to such intervals. For the purpose of this research, since the likelihood of an occurrence in such ranges is very small, an equal probability value will be assigned for each mission.

Additionally, single observations isolated from other values must be carefully

considered. Such observations might occur due to an anomalous orbit or a unique, one-time-only, mission, which places the satellite in an orbit not normally occupied. The parameter measured might then occur in an interval which is usually not occupied. For example, in the perigee range, the lowest observation occurred at 120 km, due to an anomalous launch of an ocean reconnaissance satellite. The next perigee observation was at 159 km. Normally, since no orbits under 150 km are utilized, the class interval of 150 and below might be established and any observation in the interval would be considered *unknown*. However, in using this interval, any observed value for perigee below 150 km would be considered an ocean reconnaissance mission due to the single observation at 120 km. Even though such an error might occur, the observation can not be cast aside since there is a probability that the type of *systematic* error which placed that satellite in that particular orbit might occur again. One possible way of dealing with this problem is to establish a small interval around the observed value so that if such an error reoccurred, it would not be considered unknown.

When a large continuous range of data does not have any distinct breaks where an interval can be drawn, it is possible to simply break the range into several intervals (but do not violate the above considerations). Even though this technique does not effectively distinguish mission type for that particular variable, it limits the number of possible missions in the interval and allows other variables in the model to make the mission determination.

6.4.2 Class Interval Determinations. The thought process used to determine the class intervals is now demonstrated.

- **Inclination** - Examining the mission profiles provided in Chapter IV and the range of the inclination data versus mission for the historical data, sorted ascendingly on inclination, is required in discretizing the continuous variable. The very low inclinations of the geosynchronous satellites do not exceed 2

degrees of inclination. Therefore, the low class interval for inclination was established as 0 to 3 degrees. The next set of inclinations jump to 50 degrees, so the interval 3 to 50 degrees will be considered *unknown* with each mission having an equal likelihood of occurring. The next interval is established at 51 degrees to separate manned missions from minor military and a photo reconnaissance mission. The next break in the group of inclination data is between 51.86 and 62.76 degrees with the range below this break containing mostly manned missions. The interval from 53 to 62 degrees will be considered *unknown*. The upper limit for the next interval will be 64 degrees since a large group of photo reconnaissance satellites begin at 64.75 degrees. The interval contains mostly early warning and Molniya communication satellites. The next limit is established at 65 degrees to create the interval 65 to 66 degrees capturing a group of ocean reconnaissance and minor military satellites. An interval from 70 to 72 degrees is needed to separate ELINT satellites from the higher inclined photo reconnaissance satellites. From 73 to 75 degrees of inclination the range is dominated by the low altitude communication satellites. Another section of unoccupied inclinations follows, from 75 to 81 degrees. The next break in the data occurs at approximately 83 degrees, establishing the interval 81 to 84 degrees. Since the next observation is not until 97.02 degrees, 84 to 96 degrees will be considered unknown. The maximum observation of inclination was 99.02 degrees from a remote sensing satellite. Therefore, the final interval from the observed data will be 96 to 100 degrees. Any satellite exceeding this interval will be considered unknown. Table 50 summarizes the above intervals. Note that a class interval number is also assigned to each interval. This is an additional required step when tailoring the continuous variable to the software programs *AFIDS* and *InDia*, which only accept discrete classes. Therefore, when an observation of a continuous variable is identified, the class interval number which possess the variable is input to the model.

Table 50. Class Intervals for Inclination

Class Number	Interval (Upper Limit is \leq)		
1	0	to	3 degrees
2	3	to	50 degrees
3	50	to	51 degrees
4	51	to	53 degrees
5	53	to	62 degrees
6	62	to	64 degrees
7	64	to	65 degrees
8	65	to	66 degrees
9	66	to	70 degrees
10	70	to	72 degrees
11	72	to	73 degrees
12	73	to	75 degrees
13	75	to	81 degrees
14	81	to	84 degrees
15	84	to	96 degrees
16	96	to	100 degrees
17	100	to	180 degrees

- **Perigee** - The first observation in the sorted data range of perigee, as discussed earlier, was the result of a failed upper stage. This single observation was given a forty kilometer interval from 110 to 130. The intervals from 0 to 110 km and 130 to 150 km are unoccupied. No significant breaks in the data occur over the range from 150 to 1,000 km. Photo reconnaissance satellites occupy the 150 to 400 range. The interval of 150 to 200 captures some navigation and launch vehicle test missions. 200 to 300 contains some science and ocean reconnaissance missions. Manned missions occur in the next established interval from 300 to 400 km followed by a grouping of ocean reconnaissance satellites in the 400 to 435 interval. Drawing the next interval at 500 km separates some communication and minor military satellites from a number of early warning satellites in the 500 to 600 interval. Creating a lower limit of 630 km captures a grouping of ELINT satellites. 700 to 800 contains military communication satellites, while the next interval from 800 to 900 captures another grouping of ELINTs. The weather satellites fall into the interval from 900 to 950, followed by the navigation satellites from 950 to 1,000 km. The interval from 1,110 to 1,300 contains three more weather satellites, while the range from 1,300 to 1,450 is dominated totally by military communication satellites. Drawing an interval from 1,450 to 1,550 separates some communication satellites from the geodetic satellites existing in this interval. A large gap exists between 1,500 and 19,000 which contains a single science mission is located at 1760 km. The interval from 19,000 to 19,200 contains a group of navigation satellites along with a couple of geodetic satellites. This interval is then followed by a significant empty gap from 19,200 to 35,700. At this upper limit, the geosynchronous satellites begin and continue to 35,900 km. The perigee class intervals are summarized in Table 51.
- **Apogee** - Applying the stated considerations and the above thought process used for the inclination and perigee data yielded the class intervals for apogee

Table 51. Class Intervals for Perigee

Class Number	Interval (Upper Limit is \leq)		
1	0	to	110 km
2	110	to	130 km
3	130	to	150 km
4	150	to	200 km
5	200	to	300 km
6	300	to	400 km
7	400	to	435 km
8	435	to	500 km
9	500	to	600 km
10	600	to	630 km
11	630	to	700 km
12	700	to	800 km
13	800	to	900 km
14	900	to	950 km
15	950	to	1,000 km
16	1,000	to	1,300 km
17	1,300	to	1,450 km
18	1,450	to	1,550 km
19	1,550	to	1,700 km
20	1,700	to	1,800 km
21	1,800	to	19,000 km
22	19,000	to	19,200 km
23	19,200	to	35,700 km
24	35,700	to	35,900 km
25	35,900	to	above

listed in Table 52.

- **Argument of Perigee** - This parameter is used to distinguish between the molniya communication and early warning satellites only. The intervals were created based upon the range provided by the experts interviewed. Table 53 shows these intervals.

6.5 *Probability Distribution Calculations*

A probability distribution must be calculated for each arc in the influence diagram model. The predecessor node represents the given variable and the successor node represents the conditional variable. The spreadsheet, *Lotus 1-2-3*, was used for maintaining the database of the historic satellite data and for calculating the required probability distributions. Macros were programmed in the Lotus environment to automatically calculate these distributions. Appendix A contains the model's initial probability distributions.

6.6 *Summary*

To overcome the discrete variable requirement of the software programs used, the chapter demonstrated the method of discretizing to approximate continuous variables as discrete ones. The chapter also provided illustrative examples to demonstrate how influence diagrams manipulate the underlying data structure of the graphical model to extract information represented in a form required by the decision maker. Now that the model variables have been defined, along with their interrelationships, and the probability distributions have been calculated, the model is ready to be applied towards mission prediction.

Table 52. Class Intervals for Apogee

Class Number	Interval (Upper Limit is \leq)		
1	0	to	160 km
2	160	to	200 km
3	200	to	250 km
4	250	to	275 km
5	275	to	300 km
6	300	to	350 km
7	350	to	400 km
8	400	to	500 km
9	500	to	600 km
10	600	to	700 km
11	700	to	720 km
12	720	to	780 km
13	780	to	830 km
14	830	to	900 km
15	900	to	975 km
16	975	to	1,150 km
17	1,150	to	1,300 km
18	1,300	to	1,390 km
19	1,390	to	1,500 km
20	1,500	to	1,600 km
21	1,600	to	2,250 km
22	2,250	to	2,350 km
23	2,350	to	2,600 km
24	2,600	to	17,000 km
25	17,000	to	18,000 km
26	18,000	to	19,000 km
27	19,000	to	21,000 km
28	21,000	to	35,700 km
29	35,700	to	36,000 km
30	36,000	to	38,000 km
31	38,000	to	39,000 km
32	39,000	to	40,000 km
33	40,000	to	46,700 km
34	46,700	to	46,800 km
35	46,800	to	200,000 km
36	200,000	to	203,000 km
37	203,000	to	above

Table 53. Class Intervals for Argument of Perigee

Class Number	Interval (Upper Limit is \leq)	Mission
1	0 to 275 degrees	Other
2	275 to 295 degrees	Molniya
3	295 to 310 degrees	Other
4	310 to 325 degrees	Early Warn
5	325 to 360 degrees	Other

VII. Validation and Results

7.1 Introduction

This chapter will discuss how the influence diagram model is solved to extract a Soviet satellite mission prediction given the outcome of the model variables. Limitations with the software program used to solve the model will also be discussed along with model alternatives to resolve these problems. Model validation and test results are also presented.

7.2 Solving the Model

The influence diagram model is composed of chance nodes and conditional arcs. Solving the model simply requires the reversal of the conditional arcs using *Bayes' Theorem*. The steps involved are as follows:

1. Enter the *prior probability* distribution into the chance node **MISSION**.
2. When a model variable becomes known, reverse any arcs into that specific chance node, making it unconditional.
3. To reveal the outcome of the known variable, edit the posterior distribution now present in the chance node after the completion of the arc reversals above. Assign a probability value of 1.0 to the known outcome and a 0.0 to remaining possible outcomes.
4. Reverse the arcs back into the chance node so that it has no successors. The chance node becomes *barren* and is now removed from the diagram.
5. The **MISSION** node now possesses the new probability outcomes for mission based upon the known information. As other model variables become known, repeat steps 2 to 4 for each variable and the mission probabilities will be adjusted accordingly.

7.2.1 Prior Probability Formulation. As mentioned before, formulation of the prior mission probabilities can be based upon a number of factors but the decision maker determines the final distribution to be applied. Some factors to be considered include:

- Nominal number and type of operational platforms historically maintained (ie. Nearly 50% of operational satellites are communication platforms.)
- Replacement of aged space platforms.
- Adding satellites to incomplete constellations.
- Resupply missions to *Mir*.
- Number of photo reconnaissance satellites currently operational.
- Regional conflicts and the current Soviet photo coverage.
- Soviet launch announcements.
- Intelligence information.
- Expert opinion on Soviet needs.

A probability of *zero* should not be assigned to any mission in the prior distribution. If such an assignment was made, any possibility for predicting that mission is eliminated. It is recommended that a very small probability value be assigned to unlikely missions related to a particular launch.

7.2.2 Arc Reversal from Known Chance Node. When a Soviet launch occurs, the first piece of information available is usually launch site. Therefore, the arcs into the chance node **LAUNCH SITE** must be reversed. Recall that when an arc is reversed between two chance nodes, each node inherits the other's predecessors. If the arcs from **INCLINATION** and **BOOSTER** into **LAUNCH SITE** are reversed, a number of additional probabilistic arcs are created, as shown in Figure 20. *AFIDS* was unable to reverse the arc between **LAUNCH SITE** and **BOOSTER**.

Approximately 30 minutes after initiating the arc reversal, the program generated an error message which stated: *Runtime Error 200 at 0799:321A*. The software program *InDia* was able to reverse all the arcs into **LAUNCH SITE**, however Table 54 shows the processing time required to complete the arc reversals.

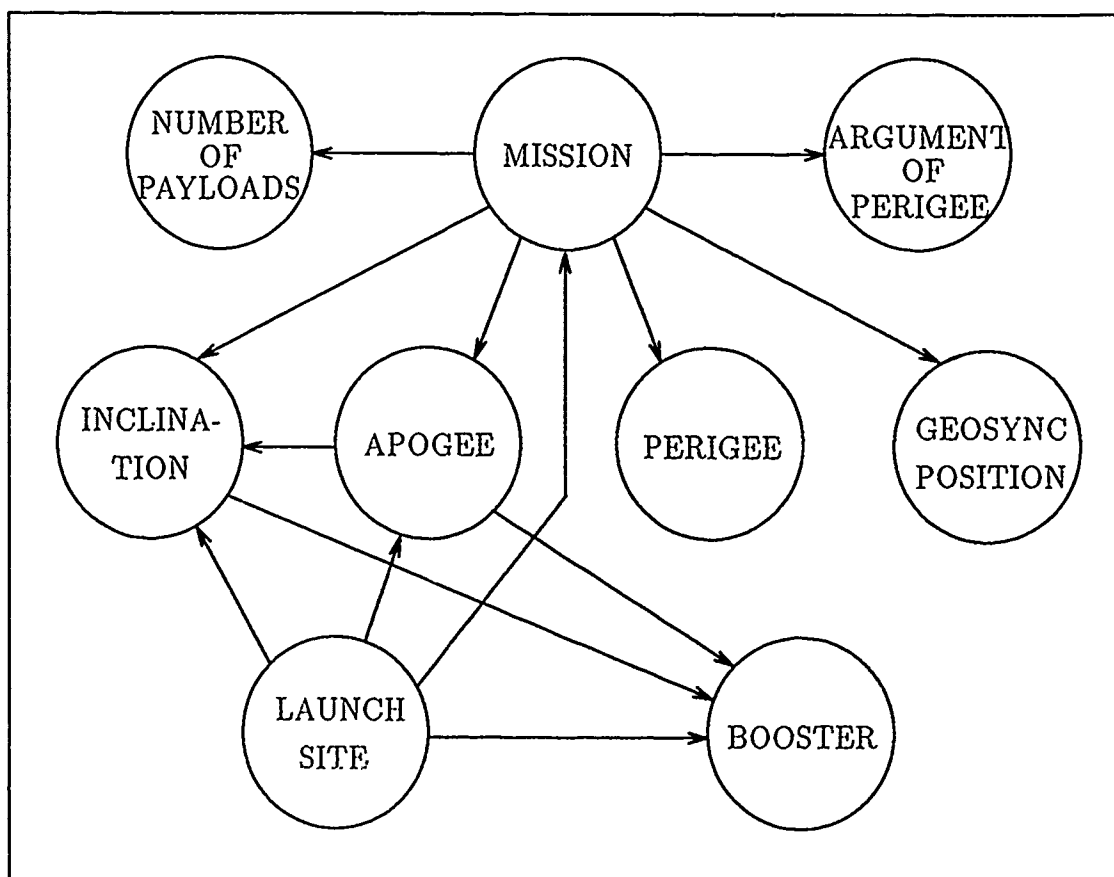


Figure 20. After Arc Reversals From Launch Site

The time required to reveal the outcome of **LAUNCH SITE** and reverse the arcs back into the node is summarized in Table 55.

After completing the above steps, the chance node **MISSION** possessed the latest probability distribution for the possible mission outcomes based upon the prior probabilities and the launch site information. The **LAUNCH SITE** chance

Table 54. Processing Time for Launch Site Arc Reversals

Arc Reversed	Processing Time (min)
BOOSTER to LAUNCH SITE	5:45
INCLINATION to LAUNCH SITE	6:05
APOGEE to LAUNCH SITE	0:30
MISSION to LAUNCH SITE	0:05

Table 55. Processing Time to Reveal Outcome of Launch Site

Arc Reversed	Processing Time (min)
LAUNCH SITE to MISSION	0:05
LAUNCH SITE to APOGEE	0:25
LAUNCH SITE to INCLINATION	6:05
LAUNCH SITE to BOOSTER	3:50

node is then removed and steps 2 to 4 are ready to be applied to the chance node **BOOSTER**. However, in attempting to reverse the arc from **INCLINATION** to **BOOSTER**, 23 minutes of processing time was required. Moreover, when attempting to reveal the outcome of **BOOSTER**, the computer produced the following error statement: *No more file handles available for allocation*. The size of the model increased from its initial size of approximately 20 kilobytes to 600 kilobytes.

7.2.2.1 Independent Model. Since the software programs were unable to process the large number of possible comes generated by the arc reversals, the next available alternative was to examine the influence of each predictive variable on the mission outcome independently. This essentially assumes that the predictive variables are dependent only upon **MISSION**. This new model is shown in Figure 21. In examining the feasibility of this assumption, a comparison of the two models was conducted.

It was assumed that a Soviet launch occurred and the actual launch site was Plesetsk. In the original model, after reversing all arcs that were into **LAUNCH SITE** (as shown in Figure 20), the **BOOSTER** node contained the possible boosters that have historically been launched from Plesetsk and the **INCLINATION** node possessed the possible inclinations from Plesetsk launches. Table 56 summarizes this information.

Table 56. Possible Inclinations and Boosters Given Site is Plesetsk

INCLINATION	BOOSTER
62 - 64 deg	SL-4
65 - 70 deg	SL-6
72 - 75 deg	SL-8
81 - 84 deg	SL-14

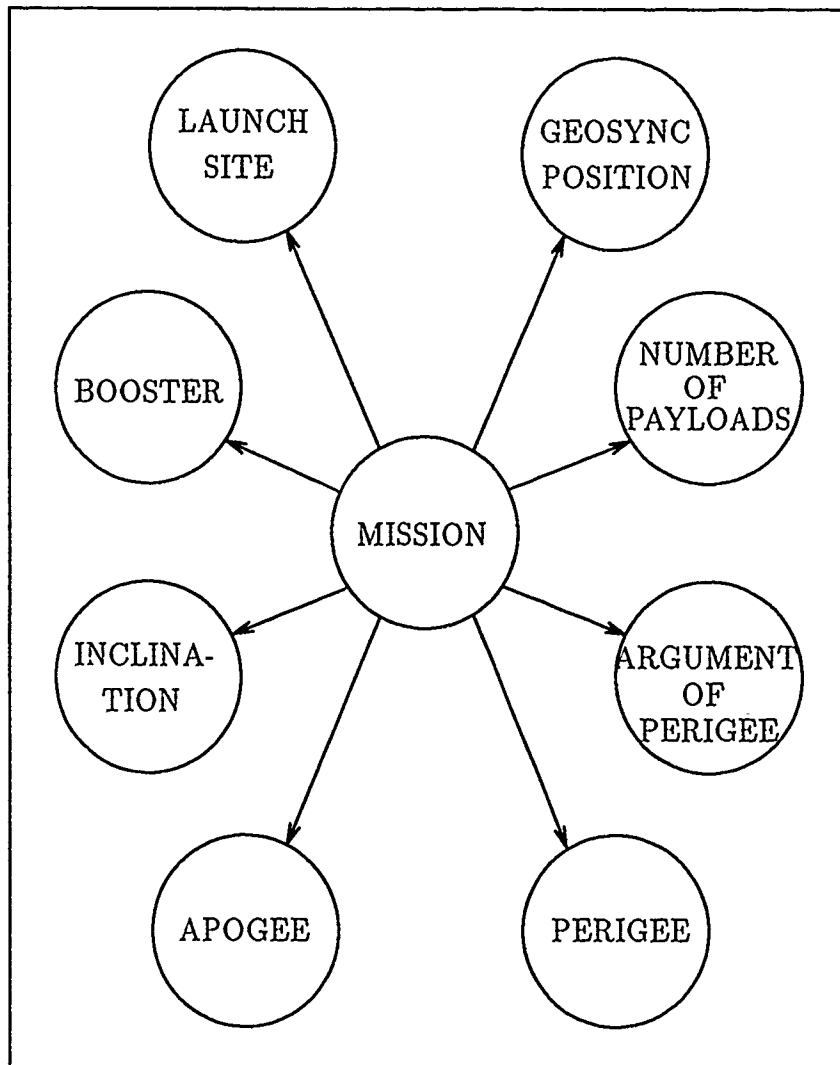


Figure 21. Independent Influence Diagram Model

The chance node **APOGEE** contained the possible apogee ranges given the possible *boosters* from Plesetsk. These values are listed in Table 57.

Table 57. Possible Apogee Ranges Given Possible Boosters

Possible Apogee Classes
200 - 720 km
780 - 1,300 km
1,390 - 1,600 km
2,250 - 2,600 km
19,000 - 21,000 km
38,000 - 46,700 km
200,000 - 203,000 km

Finally, the chance node **MISSION** possessed the possible missions given the possible *inclinations* and the possible *apogees*. However, in using the independent model, a simple arc reversal from **LAUNCH SITE** to **MISSION**, provided the possible missions given the actual *launch site*. Table 58 compares the two models' predicted missions outcomes from a Plesetsk launch.

The independent model predicted all possible missions that have been launched from Plesetsk. The original model forecasted *Manned* and *Ocean Recon* as possible missions. The independent model shows that these missions are not possible candidates for Plesetsk launches. This conflict indicates that **LAUNCH SITE** is not independent of **MISSION** (A similar test also should a dependence between **MIS- SION** and **BOOSTER**). Therefore, the original model should include an arc from **MISSION** to **LAUNCH SITE**. If this arc was included, the possible mission list for the original model would not contain manned or ocean reconnaissance missions. Therefore, the original model would list nine possible missions and the independent model would list eleven. The independent model is not as effective in predicting the possible missions since the influences of the booster, inclination, and apogee based upon launch site information are not included. However, the independent model

Table 58. Possible Apogee Ranges Given Possible Boosters

Original Model	Independent Model	Differences
COMM-CIV	COMM-CIV	GEODETIC
COMM-MIL	COMM-MIL	MANNED
EARLY WARN	EARLY WARN	OCEANOGRAPHY
ELINT	ELINT	OCEAN RECON
MANNED	GEODETIC	
METEOR	METEOR	
MINOR MIL	MINOR MIL	
NAV	NAV	
OCEAN RECON	OCEANOGRAPHY	
PHOTO	PHOTO	
SCIENCE	SCIENCE	

only requires five seconds of processing time. Additionally, when a Soviet launch occurs, the launch site information is shortly followed by the booster and inclination data. After incorporating the known booster into the model, the compared models would be very similar. Figure 22 shows these two influence diagrams.

The only difference in the two models is the arc between **INCLINATION** and **APOGEE**. Therefore, when the inclination is revealed in the original model, the possible mission outcomes would include the influence of **APOGEE** based upon the revealed inclination. The prediction, based upon this information, is slightly better than that of the independent model, however, since three predictive variables (**LAUNCH SITE, BOOSTER, INCLINATION**) have been revealed at this point, the improvement is slight. Once the apogee information is available, the model predictions become identical. Therefore, in concluding the model comparison, the corrected original model has a slight advantage in mission prediction, while the independent model is significantly faster in making a prediction.

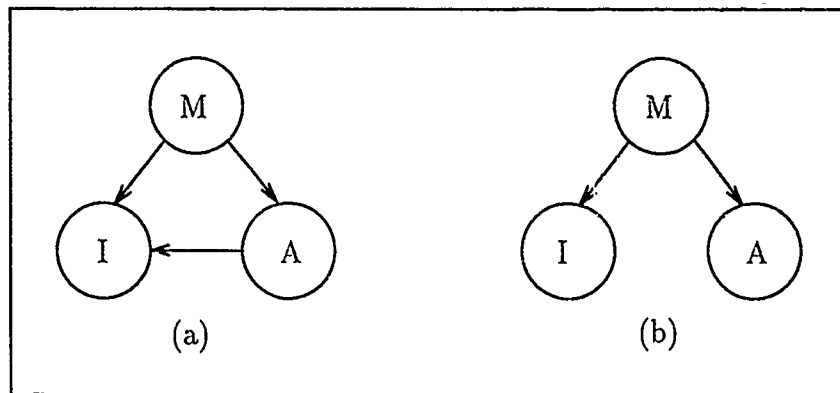


Figure 22. Models After Revealing Booster Outcome

7.3 Model Validation and Results

To validate the model, launch data to be published in *Soviet Year in Space, 1990* was obtained from Mr. Nicholas Johnson (Appendix C). Additionally, the two line element sets contain the argument of perigee values needed to supplement this data. Since the missions associated with this test data are known, it is possible to assess the predictive capability of the model. The prior distribution used assumed an equal probability for each mission. This allows for model validation in a worst case scenario where no prior information is utilized. The predictive variables were entered into the model in the following order (simulates the sequence of information arrival) until a 100% prediction probability was reached or all model information was exhausted:

1. Launch Site
2. Booster
3. Perigee
4. Apogee
5. Argument of Perigee (Molniya Orbits Only)

6. Number of Payloads

7. Geosynchronous Position (Geosynchronous Orbits Only)

Applying the required steps in solving the model, yields the results summarized in Table 59. Specific model validation assessments are now provided:

- In 28 of the 35 cases tested, the independent model was able to correctly identify the specific mission associated with the launch. Of the 7 cases in which a 100% probability prediction was not reached, the model correctly assigned the higher probability to five of these missions. Therefore, only two launches were incorrectly assessed. However, if prior information was incorporated into the prior probability distribution before the initiation of the mission assessment, the correct missions could have been identified. For example, if a 90% prior probability was assigned to both the *ELINT* mission for Launch 5 and the *photo* mission for Launch 29, the model would have predicted the correct missions, for the respective launches, to 97%.
- The effect of the prior probability distribution assignment is only important when evaluating the predicted mission probabilities after each model variable is revealed and when the model is unable to identify the unique mission associated with the launch. In cases where the mission can be 100% identified and each mission possessed an initial probability greater than one, the actual value of the prior assignment has no effect on the final outcome.
- Some missions were quickly identified. For example, the ocean reconnaissance mission of launch number 12 was identified after the launch booster was revealed. Four missions were identified after inclination was revealed. The majority of the missions (10) required at least perigee information. The launches associated with geosynchronous satellites always require the equatorial position information before being distinguished among the remote sensing and civilian

Table 59. Validation Results

Launch Number	Last Prediction Variable Applied	Actual Mission	Predicted Mission(s) (probability)
1	Apogee	PHOTO	PHOTO (1.0000)
2	Perigee	COMM-MIL	COMM-MIL (1.0000)
3	Arg of Perigee	COMM-CIV	COMM-CIV (1.0000)
4	Apogee	PHOTO	PHOTO (1.0000)
5	No of Payloads	ELINT	ELINT (0.1768) OCEANOGRAPHY (0.8232)
6	Inclination	MINOR MIL	MINOR MIL (1.0000)
7	Perigee	MANNED	MANNED (1.0000)
8	Geosync Position	COMM-MIL	COMM-MIL (1.0000)
9	Perigee	NAV	NAV (1.0000)
10	No of Payloads	OCEANOGRAPHY	OCEANOGRAPHY (0.8232) ELINT (0.1768)
11	Perigee	MANNED	MANNED (1.0000)
12	Booster	OCEAN RECON	OCEAN RECON (1.0000)
13	Perigee	NAV	NAV (1.0000)
14	Apogee	PHOTO	PHOTO (1.0000)
15	Arg of Perigee	EARLY WARN	EARLY WARN (1.0000)
16	Perigee	COMM-MIL	COMM-MIL (1.0000)
17	No of Payloads	SCIENCE	SCIENCE (0.8949) PHOTO (0.1051)
18	Apogee	PHOTO	PHOTO (1.0000)
19	Apogee	PHOTO	PHOTO (1.0000)
20	Perigee	NAV	NAV (1.0000)
21	Perigee	MINOR MIL	MINOR MIL (1.0000)
22	Arg of Perigee	COMM-CIV	COMM-CIV (1.0000)
23	Arg of Perigee	EARLY WARN	EARLY WARN (1.0000)
24	Perigee	MANNED	MANNED (1.0000)
25	Perigee	PHOTO	PHOTO (1.0000)
26	Inclination	PHOTO	PHOTO (1.0000)
27	No of Payloads	NAV	NAV (0.9821) GEODETIC (0.0179)
28	Inclination	ELINT	ELINT (1.0000)
29	No of Payloads	PHOTO	PHOTO (0.2033) SCIENCE (0.7967)
30	Inclination	MANNED	MANNED (1.0000)
31	Apogee	COMM-CIV	COMM-CIV (1.0000)
32	Apogee	PHOTO	PHOTO (1.0000)
33	Geosync Position	COMM-CIV	COMM-CIV (1.0000)
34	Perigee	EARLY WARN	EARLY WARN (0.9770) COMM-CIV (0.0230)
35	No of Payloads	METEOR	METEOR (0.9994) SCIENCE (0.0006)

and military communication missions. Molniya orbits generally require argument of perigee information, however for launch number 31, the civilian communication satellite was distinguished from an early warning mission with apogee information since it exceeded its usual apogee class interval by a very small amount placing the known apogee value in an interval without early warning observations.

- In distinguishing between oceanography and electronic intelligence missions, the model incorrectly assigned the higher probability for launch number 5, while correctly assigning a higher probability to oceanography for launch number 10. However, the Soviets currently announce when oceanographic satellites are launched. This information alone could be incorporated into the prior probability distribution, causing a low probability assignment to the oceanographic mission. Also, downlinked telemetry from the oceanographic satellites can actually be retrieved by U.S. ground stations (17). An additional means of distinguishing between the two missions would require information on the orbit's right ascension of the ascending node. This orbital measurement is time dependent and would require a significantly larger historical database than was used in this research.
- Launches 17 and 29 illustrate the problem of distinguishing between photo reconnaissance and science missions that occupy similar orbits. One discriminating factor between the two missions is that photo reconnaissance satellites undergo a number of orbital maneuvers where science missions generally do not possess maneuver capability (10). Additionally, the time of day that the launch occurred could be utilized since the Soviets, for some photo reconnaissance missions, require certain lighting conditions for recovery operations (10). An analysis of the satellite's ground trace and position versus time of day would also provide useful information. Therefore, information on the right ascension of the ascending node will help to alleviate this problem.

- For launches number 27 and 35, high probabilities were assigned to the correct missions. Both cases illustrate situations in which an orbit is dominated by a particular mission type, however, one or two observations of another mission type occur in very similar orbits.
- Launch 34, an early warning satellite, demonstrates how the model is used for a launch failure. After the perigee value was revealed in the model, the early warning probability was 0.9770 and the Molniya civilian communication probability was 0.0230. Since the satellite failed to reach the proper apogee height, when the apogee value was revealed, the model did not find a launch and orbit combination that matched any historical Soviet launches. In this situation, the model returns a distribution that each mission is equally likely to occur. When the decision maker reaches this point, the best alternative available is to return to the distribution produced by the previous model parameter.

7.4 *Summary*

This chapter demonstrated how the influence diagram model is applied towards predicting the mission associated with a Soviet launch. Due to software limitations, an assumption of variable independence had to be made. The model was validated using 1990 launch data and the results were presented and analyzed. The final chapter will summarize the overall research effort of this thesis.

VIII. *Conclusions and Recommendations*

8.1 *Introduction*

The purpose of this thesis research was to demonstrate the applicability of using influence diagramming towards the development of a Soviet satellite mission prediction model. The model captured the influence of launch information and certain orbital parameters to reduce the uncertainty of the satellite's mission. Using 1990 Soviet launch information, the model's predictive power was successfully demonstrated. Additionally, since the model is capable of assessing mission outcome probabilities with each introduction of additional information, the model is capable of being applied to the development of an ASAT decision model.

8.2 *Conclusions*

Influence diagrams are an effective tool for constructing a satellite prediction model. The use of successively revealed information effectively refined the estimate of the probable mission and helped reduce the uncertainty in the model. The model was able to accurately predict the mission in 28 of 35 test cases. Furthermore, if the adjusted prior probability is used, versus the worst case scenario of applying a equiprobable prior, the accuracy is increased to 100%.

Software limitations of *AFIDS* and *InDia* prevented the generation of results from the initial influence diagram model. Arc reversals in this model, created a significantly large number of outcomes to a magnitude which exceeded the data storage and computational capabilities of the software programs. An assumption of independence among the predictive model variables was applied to create an alternative influence diagram model. Additionally, the *reveal* function of *AFIDS* does not function properly.

The predictive model is flexible. Influence diagrams provided an effective means for incorporating expert knowledge and decision theory in a number of different ways.

Discretizing allowed the use of both discrete and continuous variables in a single model. This process proved to be an effective technique of adapting the continuous variables to the restrictions of the influence diagramming rule of using only one type of variable in a single model and the software requirement of using only discrete variables.

The predictive influence diagram model can be adapted towards the development of an ASAT engagement decision model. The use of decision and value nodes introduced in Chapter VI, along with the predictive capabilities of the tested model, provide a foundation in which a decision maker can collectively organize decision rules and utility values to evaluate possible engagement outcomes.

8.3 Recommendations

To improve upon the tested influence diagram model, the following recommendations are made:

1. Research new and more efficient methods for determining probabilities. For example, development of a software program which is capable of estimating the probability density functions of the model's continuous variables to allow the control of *Type I* and *Type II* errors. Additionally, investigation of possible heuristics or algorithms in the field of artificial intelligence could overcome the software problems encountered in this research.
2. Explore the possible addition of time related model variables, such as launch time and right ascension of the ascending node to improve the predictive capability of the model. This would require expansion of the historical database and/or additional expert information.

3. Using the predictive model, fully develop an ASAT decision model.
4. Research the development of a hybrid influence diagram model which allows the use of both discrete and continuous variables in a single diagram.
5. Develop an expert system based upon the use of influence diagrams and the probability approach applied in this thesis. Testing and validation yielded a number of cases where the mission probability goes to 1.0. This reduction of uncertainty as information becomes available forms a foundation for the development of an expert system.

8.4 Summary

This thesis demonstrated that influence diagram models can be used to capture expert knowledge and construct a graphical model which illustrates the probabilistic relationships of the model variables and also provide a mathematically concise structure for computationally manipulating the underlying data structure to extract information in a usable form.

Appendix A. Model Probability Distributions

A.1 Inclination Given Mission

Inclination	Mission:								
	Comm-C	Comm-M	E-Warn	Elint	Geodet	LV Test	Man	Mars	Meteor
3	0.4706	0.0756	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
50	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
51	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
53	0.0196	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	1.0000	0.0000
62	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
64	0.5098	0.0084	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
65	0.0000	0.0000	0.0000	0.0000	0.2500	0.8000	0.0000	0.0000	0.0000
66	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
70	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
72	0.0000	0.0000	0.0000	0.2500	0.0000	0.0000	0.0000	0.0000	0.0000
73	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
75	0.0000	0.5630	0.0000	0.0000	0.6250	0.0000	0.0000	0.0000	0.0000
81	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
84	0.0000	0.3529	0.0000	0.7500	0.1250	0.0000	0.0000	0.0000	1.0000
96	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
100	0.0000	0.0000	0.0000	0.0000	0.0000	0.2000	0.0000	0.0000	0.0000

Inclination	Mission:							
	Min-Mil	Nav	O-Recon	Oceanog	Photo	Rem-Sen	Scien	Unknown
3	0.0000	0.0000	0.0000	0.0000	0.0000	0.2000	0.0000	0.0000
50	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
51	0.1429	0.0000	0.0000	0.0000	0.0063	0.0000	0.0000	0.0000
53	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0588	0.0000
62	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
64	0.0000	0.0000	0.0000	0.0000	0.0818	0.0000	0.3529	0.0000
65	0.0000	0.5283	0.3636	0.0000	0.2013	0.0000	0.0588	1.0000
66	0.5714	0.0000	0.5909	0.0000	0.0000	0.0000	0.0000	0.0000
70	0.0000	0.0000	0.0000	0.0000	0.1950	0.0000	0.0000	0.0000
72	0.0000	0.0000	0.0000	0.0000	0.0343	0.2000	0.0000	0.0000
73	0.0000	0.0000	0.0000	0.0000	0.2138	0.0000	0.0000	0.0000
75	0.2857	0.0000	0.0455	0.0000	0.0000	0.0000	0.0000	0.0000
81	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
84	0.0000	0.4717	0.0000	1.0000	0.2075	0.0000	0.5204	0.0000
96	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
100	0.0000	0.0000	0.0000	0.0000	0.0000	0.6000	0.0000	0.0000

A.2 Apogee Given Mission

Apogee	Mission:								
	Comm-C	Comm-M	E-Warn	Elint	Geodet	LV Test	Man	Mars	Meteor
160	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
200	0.0000	0.0000	0.0000	0.0000	0.0000	0.2000	0.0000	1.0000	0.0000
250	0.0196	0.0100	0.0000	0.0000	0.0000	0.2000	0.0000	0.0000	0.0000
275	0.0000	0.0000	0.0000	0.0000	0.0000	0.4000	0.0270	0.0000	0.0000
300	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
350	0.0000	0.0000	0.0000	0.0000	0.0000	0.2000	0.2432	0.0000	0.0000
400	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.7297	0.0000	0.0000

500	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
600	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
700	0.0000	0.0000	0.0000	0.7500	0.0000	0.0000	0.0000	0.0000	0.0000
720	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
780	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
830	0.0000	0.0924	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
900	0.0000	0.0000	0.0000	0.2500	0.0000	0.0000	0.0000	0.0000	0.0000
975	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.7000
1150	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1300	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.3000
1390	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1500	0.0000	0.7647	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1600	0.0000	0.0588	0.0000	0.0000	0.7500	0.0000	0.0000	0.0000	0.0000
2250	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2350	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2600	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
17000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
18000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
19000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
21000	0.0000	0.0000	0.0435	0.0000	0.2500	0.0000	0.0000	0.0000	0.0000
35700	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
36000	0.4706	0.0756	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
38000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
39000	0.0000	0.0000	0.0435	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
40000	0.4902	0.0084	0.9130	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
46700	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
46800	0.0196	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
200000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
203000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Apogee	Missions:							
	Min-Mil	Nav	O-Recon	Oceanog	Photo	Rem-Sen	Scien	Unknown
160	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
200	0.0000	0.0586	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
250	0.0000	0.0000	0.0000	0.0000	0.0126	0.0000	0.0000	0.0000
275	0.0000	0.0000	0.3182	0.0000	0.2201	0.2000	0.3529	0.0000
300	0.0000	0.0000	0.0000	0.0000	0.2138	0.0000	0.0000	0.0000
350	0.0000	0.0000	0.0000	0.0000	0.1887	0.0000	0.0000	0.0000
400	0.0000	0.0000	0.0455	0.0000	0.1698	0.0000	0.3529	0.0000
500	0.1429	0.0000	0.5455	0.0000	0.1950	0.0000	0.0000	0.0000
600	0.7143	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
700	0.0000	0.0000	0.0000	1.0000	0.0000	0.4000	0.0000	0.0000
720	0.0714	0.0000	0.0000	0.0000	0.0000	0.0000	0.9000	0.0000
780	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
830	0.0000	0.0000	0.0909	0.0000	0.0000	0.0000	0.6000	0.0000
900	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
975	0.0000	0.0000	0.0000	0.0000	0.0000	0.2000	0.0588	0.0000
1150	0.0000	0.4717	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1300	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1390	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1500	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1600	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2250	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2350	0.0714	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2600	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1176	1.0000
17000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

18000	0.0000	0.0566	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
19000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
21000	0.0000	0.4151	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
35700	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
36000	0.0000	0.0000	0.0000	0.0000	0.0000	0.2000	0.0000	0.0000
38000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
39000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
40000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
46700	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
46800	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
200000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
203600	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1176	0.0000

A.3 Perigee Given Mission

Mission:									
Perigee	Comm-C	Comm-M	E-Warn	Elint	Geodet	LV Test	Man	Mars	Meteor
110	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
130	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
150	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
200	0.0196	0.0000	0.0000	0.0357	0.0000	1.0000	0.0000	1.0000	0.0000
300	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0541	0.0000	0.0000
400	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9459	0.0000	0.0000
435	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
500	0.1765	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
600	0.0784	0.0000	0.3913	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
630	0.1569	0.0084	0.5217	0.0714	0.0000	0.0000	0.0000	0.0000	0.0000
700	0.0980	0.0000	0.0870	0.6786	0.0000	0.0000	0.0000	0.0000	0.0000
800	0.0000	0.0024	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
900	0.0000	0.0000	0.0000	0.2143	0.0000	0.0000	0.0000	0.0000	0.0000
950	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.7000
1000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1300	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.3000
1450	0.0000	0.0050	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1550	0.0000	0.2185	0.0000	0.0000	0.7500	0.0000	0.0000	0.0000	0.0000
1700	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1800	0.0000	0.0000	0.0000	0.3000	0.0000	0.0000	0.0000	0.0000	0.0000
19000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
19200	0.0000	0.0000	0.0000	0.0000	0.2500	0.0000	0.0000	0.0000	0.0000
35700	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
35900	0.4706	0.0756	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Mission:								
Perigee	Min-Mil	Nav	O-Recon	Oceanog	Photo	Rem-Sen	Scien	Unknown
110	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
130	0.0000	0.0000	0.0455	0.0000	0.0000	0.0000	0.0000	0.0000
150	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
200	0.0714	0.1132	0.0000	0.0000	0.2767	0.0000	0.0000	1.0000
300	0.0714	0.0000	0.3182	0.0000	0.4906	0.2000	0.7059	0.0000
400	0.2857	0.0000	0.0000	0.0000	0.2327	0.0000	0.0000	0.0000
435	0.0000	0.0000	0.5455	0.0000	0.0000	0.0000	0.0588	0.0000
500	0.4286	0.0000	0.0000	0.0000	0.0000	0.0000	0.1176	0.0000
600	0.1429	0.0000	0.0000	0.0000	0.0000	0.2000	0.0000	0.0000
630	0.0000	0.0000	0.0000	0.0000	0.0000	0.2000	0.0000	0.0000

700	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000
800	0.0000	0.0000	0.0909	0.0000	0.0000	0.0000	0.0000	0.0000
900	0.0000	0.0000	0.0000	0.0000	0.0000	0.2000	0.0000	0.0000
950	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0588	0.0000
1000	0.0000	0.4717	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1300	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1450	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1550	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1700	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1800	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0588	0.0000
19000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
19200	0.0000	0.4151	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
35700	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
35900	0.0000	0.0000	0.0000	0.0000	0.0000	0.2000	0.0000	0.0000

A.4 Argument of Perigee Given Mission

Arg of Perigee	Mission:								
	Comm-C	Comm-M	E-Warn	Elint	Geodet	LV Test	Man	Mars	Meteor
270	0.0000	0.2000	0.0000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000
290	1.0000	0.2000	0.0000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000
305	0.0000	0.2000	0.0000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000
325	0.0000	0.2000	1.0000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000
360	0.0000	0.2000	0.0000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000

Arg of Perigee	Mission:							
	Min-Mil	Nav	O-Recon	Oceanog	Photo	Rem-Sen	Scien	Unknown
270	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000
290	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000
305	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000
325	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000
360	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000

A.5 No of Payloads Given Mission

Number of Payloads	Mission:								
	Comm-C	Comm-M	E-Warn	Elint	Geodet	LV Test	Man	Mars	Meteor
1	1.0000	0.1765	1.0000	1.0000	0.7500	1.0000	1.0000	1.0000	1.0000
2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3	0.0000	0.0000	0.0000	0.0000	0.2500	0.0000	0.0000	0.0000	0.0000
6	0.0000	0.3529	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
8	0.0000	0.4706	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Number of Payloads	Mission:							
	Min-Mil	Nav	O-Recon	Oceanog	Photo	Rem-Sen	Scien	Unknown
1	1.0000	0.4717	1.0000	1.0000	0.9874	1.0000	0.6471	1.0000
2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1176	0.0000
3	0.0000	0.5283	0.0000	0.0000	0.0126	0.0000	0.2353	0.0000
6	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
8	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

A.6 Geosynchronous Position Given Apogee

Mission:									
Geo Position	Comm-C	Comm-M	E-Warn	Elint	Geodet	LV Test	Man	Mars	Meteor
35.0	0.0000	0.1111	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
40.0	0.0588	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
45.0	0.0000	0.2222	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
49.0	0.0000	0.1111	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
53.0	0.0588	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
70.0	0.0000	0.1111	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
80.0	0.1176	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
85.0	0.0000	0.1111	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
90.0	0.0588	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
95.0	0.0588	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
96.5	0.0588	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
99.0	0.1765	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
103.0	0.0588	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
128.0	0.0000	0.1111	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
140.0	0.0588	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
190.0	0.0588	0.1111	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
335.0	0.0588	0.1111	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
336.0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
346.0	0.1176	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
349.0	0.0588	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
N/A	0.0000	0.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

Mission:								
Geo Position	Min-Mil	Nav	O-Recon	Oceanog	Photo	Rem-Sen	Scien	Unknown
35.0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
40.0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
45.0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
49.0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
53.0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
70.0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
80.0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
85.0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
90.0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
95.0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
96.5	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
99.0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
103.0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
128.0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
140.0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
190.0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
335.0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
336.0	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000
346.0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
349.0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
N/A	1.0000	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000

A.7 Booster Given Apogee

Apogee:												
Booster	160	200	270	300	350	400	500	600	700	720	780	830
SL-3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0769	0.0000	0.0000	0.0000

SL-4	0.0000	0.0000	0.6250	0.9828	0.9500	0.9344	0.6889	0.0000	0.0000	0.0000	0.0000	0.0000
SL-6	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SL-8	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0444	0.8000	0.0000	1.0000	0.0000	0.8462
SL-11	0.0000	0.0000	0.1875	0.0172	0.0000	0.0164	0.2667	0.0000	0.0000	0.0000	0.0000	0.1538
SL-12	0.0000	0.8333	0.0313	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SL-13	0.0000	0.0000	0.0313	0.0000	0.0250	0.0492	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SL-14	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.2000	0.9231	0.0000	0.0000	0.0000
SL-16	0.0000	0.1667	0.0938	0.0000	0.0250	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SL-17	0.0000	0.0000	0.0313	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Booster	Apogee:											
	900	975	1150	1300	1390	1500	1600	2250	2350	2600	17000	18000
SL-3	0.0000	0.1111	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SL-4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SL-6	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SL-8	0.0000	0.0000	1.0000	0.0000	0.0000	0.5385	0.5385	0.0000	1.0000	0.0000	0.0000	0.0000
SL-11	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SL-12	0.1429	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000
SL-13	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SL-14	0.0000	0.8889	0.0000	1.0000	0.0000	0.4615	0.4615	0.0000	0.0000	0.6667	0.0000	0.0000
SL-16	0.8571	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.3333	0.0000	0.0000
SL-17	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Booster	Apogee:										
	19000	21000	35700	36000	38000	39000	40000	46700	46800	200000	203000
SL-3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SL-4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SL-6	0.0000	0.0400	0.0000	0.0000	0.0000	1.0000	1.0000	0.0000	1.0000	0.0000	0.5000
SL-8	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SL-11	0.0000	0.0000	0.0900	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SL-12	0.0000	0.9600	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.5000
SL-13	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SL-14	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SL-16	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0900	0.0000	0.0000
SL-17	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

A.8 Launch Site Given Inclination and Booster

BOOSTER SL-3													
INCLINATION													
SITE	3.00	50.00	53.00	62.00	64.00	65.00	66.00	70.00	72.00	73.00	75.00	81.00	84.00 96.00 100.00
TT	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333 1.0000
PL	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333 0.0000
KY	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333 0.0000

BOOSTER SL-4													
INCLINATION													
SITE	3.00	50.00	53.00	62.00	64.00	65.00	66.00	70.00	72.00	73.00	75.00	81.00	84.00 96.00 100.00
TT	0.3333	0.3333	1.0000	0.3333	0.0000	1.0000	0.3333	0.4194	1.0000	0.0000	0.3333	0.3333	0.0000 0.3333 0.3333
PL	0.3333	0.3333	0.0000	0.3333	1.0000	0.0000	0.3333	0.5806	0.0000	1.0000	0.3333	0.3333	1.0000 0.3333 0.3333

KY	0.3333	0.3333	0.0000	0.3333	0.0000	0.0000	0.3333	0.0000	0.0000	0.0000	0.3333	0.3333	0.0000	0.3333	0.3333
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BOOSTER SL-6
INCLINATION

SITE	3.00	50.00	53.00	62.00	64.00	65.00	66.00	70.00	72.00	73.00	75.00	81.00	84.00	96.00	100.00
TT	0.3333	0.3333	0.3333	0.3333	0.0600	1.0000	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333
PL	0.3333	0.3333	0.3333	0.3333	0.9400	0.0000	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333
KY	0.3333	0.3333	0.3333	0.3333	0.0000	0.0000	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333

BOOSTER SL-8
INCLINATION

SITE	3.00	50.00	53.00	62.00	64.00	65.00	66.00	70.00	72.00	73.00	75.00	81.00	84.00	96.00	100.00
TT	0.3333	0.3333	0.0000	0.3333	0.3333	0.3333	0.0000	0.3333	0.3333	0.3333	0.0000	0.3333	0.0000	0.3333	0.3333
PL	0.3333	0.3333	0.0000	0.3333	0.3333	0.3333	1.0000	0.3333	0.3333	0.3333	1.0000	0.3333	1.0000	0.3333	0.3333
KY	0.3333	0.3333	1.0000	0.3333	0.3333	0.3333	0.0000	0.3333	0.3333	0.3333	0.0000	0.3333	0.0000	0.3333	0.3333

BOOSTER SL-11
INCLINATION

SITE	3.00	50.00	53.00	62.00	64.00	65.00	66.00	70.00	72.00	73.00	75.00	81.00	84.00	96.00	100.00
TT	0.3333	0.3333	0.3333	0.3333	0.3333	1.0000	1.0000	0.3333	0.3333	0.3333	1.0000	0.3333	0.3333	0.3333	0.3333
PL	0.3333	0.3333	0.3333	0.3333	0.3333	0.0000	0.0000	0.3333	0.3333	0.3333	0.0000	0.3333	0.3333	0.3333	0.3333
KY	0.3333	0.3333	0.3333	0.3333	0.3333	0.0000	0.0000	0.3333	0.3333	0.3333	0.0000	0.3333	0.3333	0.3333	0.3333

BOOSTER SL-12
INCLINATION

SITE	3.00	50.00	53.00	62.00	64.00	65.00	66.00	70.00	72.00	73.00	75.00	81.00	84.00	96.00	100.00
TT	1.0000	0.3333	1.0000	0.3333	0.3333	1.0000	0.3333	0.3333	1.0000	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333
PL	0.0000	0.3333	0.0000	0.3333	0.3333	0.0000	0.3333	0.3333	0.0000	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333
KY	0.0000	0.3333	0.0000	0.3333	0.3333	0.0000	0.3333	0.3333	0.0000	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333

BOOSTER SL-13
INCLINATION

SITE	3.00	50.00	53.00	62.00	64.00	65.00	66.00	70.00	72.00	73.00	75.00	81.00	84.00	96.00	100.00
TT	0.3333	0.3333	1.0000	0.3333	0.3333	0.3333	0.3333	0.3333	1.0000	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333
PL	0.3333	0.3333	0.0000	0.3333	0.3333	0.3333	0.3333	0.3333	0.0000	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333
KY	0.3333	0.3333	0.0000	0.3333	0.3333	0.3333	0.3333	0.3333	0.0000	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333

BOOSTER SL-14
INCLINATION

SITE	3.00	50.00	53.00	62.00	64.00	65.00	66.00	70.00	72.00	73.00	75.00	81.00	84.00	96.00	100.00
TT	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.0000	0.3333	0.0000	0.3333	0.3333
PL	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	1.0000	0.3333	1.0000	0.3333	0.3333
KY	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.0000	0.3333	0.0000	0.3333	0.3333

BOOSTER SL-16

INCLINATION																
SITE	3.00	50.00	53.00	62.00	64.00	65.00	66.00	70.00	72.00	73.00	75.00	81.00	84.00	96.00	100.00	
TT	0.3333	0.3333	0.3333	0.3333	0.3333	1.0000	0.3333	0.3333	1.0000	0.3333	0.3333	0.3333	0.3333	0.3333	1.0000	
PL	0.3333	0.3333	0.3333	0.3333	0.3333	0.0000	0.3333	0.3333	0.0000	0.3333	0.3333	0.3333	0.3333	0.3333	0.0000	
KY	0.3333	0.3333	0.3333	0.3333	0.3333	0.0000	0.3333	0.3333	0.0000	0.3333	0.3333	0.3333	0.3333	0.3333	0.0000	

BOOSTER SL-17																
INCLINATION																
SITE	3.00	50.00	53.00	62.00	64.00	65.00	66.00	70.00	72.00	73.00	75.00	81.00	84.00	96.00	100.00	
TT	0.3333	0.3333	1.0000	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	
PL	0.3333	0.3333	0.0000	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	
KY	0.3333	0.3333	0.0000	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	

Appendix B. *Independent Model Distribution Additions*

B.1 *Booster Given Mission*

Booster	Mission:								
	Comm-C	Comm-M	E-Warn	Elint	Geodet	LV Test	Man	Mars	Meteor
SL-3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SL-4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.8649	0.0000	0.0000
SL-6	0.5098	0.0084	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SL-8	0.0000	0.5630	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SK-11	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SL-12	0.4902	0.0756	0.0000	0.0357	0.2500	0.0000	0.0000	1.0000	0.0000
SL-13	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1081	0.0000	0.0000
SL-14	0.0000	0.3529	0.0000	0.7500	0.7500	0.0000	0.0000	0.0000	1.0000
SL-16	0.0000	0.0000	0.0000	0.2143	0.0000	1.0000	0.0000	0.0000	0.0000
SL-17	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0270	0.0000	0.0000

Booster	Mission:							
	Min-Mil	Nav	O-Recon	Oceanog	Photo	Rem-Sen	Scien	Unknown
SL-3	0.0000	0.0000	0.0000	0.0000	0.0000	0.6000	0.0000	0.0000
SL-4	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.7059	0.0000
SL-6	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0588	0.0000
SL-8	0.8571	0.4717	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SK-11	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SL-12	0.0000	0.5283	0.0000	0.0000	0.0000	0.2000	0.0588	0.0000
SL-13	0.0000	0.0000	0.0000	0.0000	0.0000	0.2000	0.0000	0.0000
SL-14	0.1429	0.0000	0.0000	1.0000	0.0000	0.0000	0.1765	0.0000
SL-16	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000
SL-17	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

B.2 *Launch Site Given Mission*

Site	MISSION:								
	Comm-C	Comm-M	E-Warn	Elint	Geodet	LV Test	Man	Mars	Meteor
TT	0.5490	0.0756	0.0000	0.2500	0.2500	1.0000	1.0000	1.0000	0.0000
PL	0.4510	0.9244	1.0000	0.7500	0.7500	0.0000	0.0000	0.0000	1.0000
KY	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

SITE	Mission:							
	Min-Mil	Nav	O-Recon	Oceanog	Photo	Rem-Sen	Scien	Unknown
TT	0.0000	0.5283	1.0000	0.0000	0.3836	1.0000	0.1176	1.0000
PL	0.8571	0.4717	0.0000	1.0000	0.6164	0.0000	0.8824	0.0000
KY	0.1429	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Appendix C. Test Data

Soviet Launch History, 1990										
No	Name	Date	Time	Site	Booster	Apogee (km)	Perigee (km)	Period (min)	Inclin (deg)	Mission
1	KOSMOS 2055	17-Jan-90	14:38:24	PL	SL-4	321	249	90.21	62.83	PHOTO
2	KOSMOS 2056	18-Jan-90	12:57:36	PL	SL-8	810	776	100.72	74.04	COMM-MIL
3	MOLNIYA 3-37	23-Jan-90	02:52:46	PL	SL-6	39749	598	717.63	62.80	COMM-CIV
4	KOSMOS 2057	25-Jan-90	17:02:24	PL	SL-4	327	188	69.65	62.84	PHOTO
5	KOSMOS 2058	30-Jan-90	11:16:48	PL	SL-14	665	634	97.71	82.51	ELINT
6	KOSMOS 2059	06-Feb-90	16:33:36	PL	SL-8	2281	190	110.19	65.84	MINOR MIL
7	SOYUZ TM-9	11-Feb-90	06:43:12	TT	SL-4	407	382	92.45	51.62	MANNED
8	RADUGA 26	15-Feb-90	07:55:12	TT	SL-12	35810	35771	1436.28	1.46	COMM-MIL
9	NADEZHDA 2	27-Feb-90	21:07:12	PL	SL-6	1020	958	104.87	82.96	NAV
10	OKEAN 2	28-Feb-90	00:57:36	PL	SL-14	666	639	97.78	82.53	REMOTE SEN
11	PROGRESS M-3	28-Feb-90	23:16:48	TT	SL-4	402	379	92.36	51.62	MANNED
12	KOSMOS 2060	14-Mar-90	15:21:36	TT	SL-11	417	404	92.78	65.03	OCEAN RECON
13	KOSMOS 2061	20-Mar-90	00:28:48	PL	SL-8	1017	973	105.01	82.94	NAV
14	KOSMOS 2062	22-Mar-90	07:26:24	PL	SL-4	248	211	89.09	32.33	PHOTO
15	KOSMOS 2063	27-Mar-90	16:33:36	PL	SL-6	39739	608	717.64	62.81	EARLY WARN
16	KOSMOS 2064	06-Apr-90	03:21:36	PL	SL-8	1491	1463	115.48	73.98	COMM-MIL
16	KOSMOS 2065	06-Apr-90	03:21:36	PL	SL-8	1476	1462	115.29	73.98	COMM-MIL
16	KOSMOS 2066	06-Apr-90	03:21:36	PL	SL-8	1463	1387	114.33	73.98	COMM-MIL
16	KOSMOS 2067	06-Apr-90	03:21:36	PL	SL-8	1463	1401	114.49	73.98	COMM-MIL
16	KOSMOS 2068	06-Apr-90	03:21:36	PL	SL-8	1463	1415	114.65	73.98	COMM-MIL
16	KOSMOS 2069	06-Apr-90	03:21:36	PL	SL-8	1463	1430	114.80	73.98	COMM-MIL
16	KOSMOS 2070	06-Apr-90	03:21:36	PL	SL-8	1463	1444	144.96	73.98	COMM-MIL
16	KOSMOS 2071	06-Apr-90	03:21:36	PL	SL-8	1463	1460	115.13	73.98	COMM-MIL
17	PHOTON 3	11-Apr-90	17:02:24	PL	SL-4	376	217	90.45	62.80	SCIENCE
18	KOSMOS 2072	13-Apr-90	18:57:36	TT	SL-4	288	241	89.79	64.76	PHOTO
19	KOSMOS 2073	17-Apr-90	07:55:12	PL	SL-4	298	233	69.82	82.36	PHOTO
20	KOSMOS 2074	20-Apr-90	18:43:12	PL	SL-8	1005	967	104.83	82.95	NAV
21	KOSMOS 2075	25-Apr-90	12:57:36	PL	SL-8	515	484	94.60	74.02	MINOR MIL
22	MOLNIYA 1-77	26-Apr-90	01:40:48	PL	SL-6	39724	631	717.78	62.80	COMM-CIV
23	KOSMOS 2076	28-Apr-90	11:02:24	PL	SL-6	38774	581	717.77	63.04	EARLY WARN
24	PROGRESS 42	05-May-90	20:38:24	TT	SL-4	389	389	92.37	51.62	MANNED
25	KOSMOS 2077	07-May-90	18:28:48	PL	SL-4	375	174	80.00	62.84	PHOTO
26	KOSMOS 2078	15-May-90	10:04:48	TT	SL-4	278	213	89.41	69.99	PHOTO
27	KOSMOS 2079	19-May-90	08:38:24	TT	SL-12	19185	19075	675.73	64.90	NAV
27	KOSMOS 2080	19-May-90	08:38:24	TT	SL-12	19152	19108	675.73	64.89	NAV
27	KOSMOS 2081	19-May-90	08:38:24	TT	SL-12	19160	19099	675.73	64.91	NAV
28	KOSMOS 2082	22-May-90	05:31:12	TT	SL-16	855	849	101.97	71.00	ELINT
29	RESURS-F 8	29-May-90	07:26:24	PL	SL-4	272	259	89.82	82.34	PHOTO
30	KRISTALL	31-May-90	10:33:36	TT	SL-13	392	377	92.24	51.81	MANNED
31	MOLNIYA 3-36	13-Jun-90	00:57:36	PL	SL-6	39888	484	717.73	62.83	COMM-CIV
32	KOSMOS 2083	19-Jun-90	08:52:48	PL	SL-4	412	298	91.65	82.59	PHOTO
33	GORIZONT 20	20-Jun-90	23:31:12	TT	SL-12	35865	35715	1436.29	1.49	COMM-CIV
34	KOSMOS 2084	21-Jun-90	20:38:24	PL	SL-6	758	586	98.19	62.81	EARLY WARN
35	METEOR 2-19	27-Jun-90	22:33:36	PL	SL 14	961	939	104.66	62.55	METEOR

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